SCOTTISH FUTURES TRUST

North-Eastern Scotland: Subsea Connectivity Feasibility Study

By FarrPoint and Pioneer Consulting

Contents

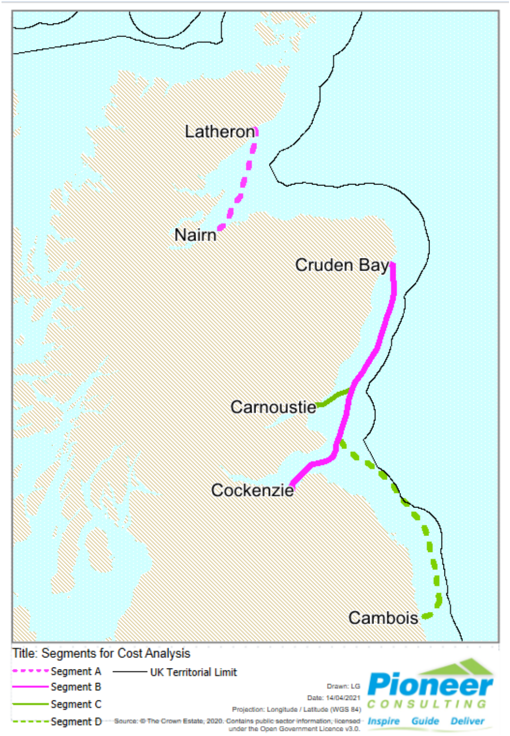
1. Executive Summary

Scottish Futures Trust (SFT) commissioned this report to investigate the cost, complexity and deliverability of a number of subsea fibre options from the North coast of Scotland to Edinburgh. The analysis within this report focuses on the cable route options using a three-stage approach to identify the technical requirements, to carry out spatial analysis, and to identify potential and subsequent high-level costings.

The initial proposed routes were provided by SFT as part of the commission and these routes have been investigated in full, with the exception of the following amendments agreed with SFT:

- Given the high energy environment and rock seabed of the Pentland Firth, it is recommended to avoid routing south from Thurso through the Firth, and instead use onshore cabling to Latheron from where subsea will commence; and
- The requested route overlaps with twelve pipelines at Cruden Bay (Nigg) which would require extensive concrete mattressing and numerous commercially disadvantageous crossing agreements. This is likely to be unacceptable to both the fishing community (in terms of breaking up and dispersing across the seabed) and the licensing authority. The proposed route therefore travels onshore from Nairn to south of Cruden Bay to avoid this area.

This report provides a number of technical solutions for optical capacity and connectivity appropriate to the route options and marine environment. The final route options and costs are shown as follows:



Segment Description	Costing
Latheron ➔ Nairn (pink dotted)	£5,320,000
Cruden Bay ➔ Cockenzie (pink solid)	£12,120,000
Cruden Bay ➔ Cockenzie, branch to Carnoustie (pink solid & green solid)	£14,230,000
Cruden Bay ➔ Cambois, branches to Carnoustie & Cockenzie (pink solid, green solid & green dashed)	£25,340,000

Table 1: Segment Costs

Figure 1: (Left) Proposed Hybrid Solution

Should these routes wish to be pursued, the next steps are to discuss with the relevant affected stakeholders to explore sharing, both the terrestrial and marine space, and with the Scottish Government Licensing Team to underpin the requirements for survey and installation.

2. Introduction

2.1. Scope of Study

The Scottish Government's March 2021 Digital Strategy aims to create a more sustainable and successful Scotland through promoting inclusive economic growth. One of the key enablers of this ambition is investing in digital and telecommunications infrastructure, such as data centres and subsea cables landing in Scotland. This Strategy document aligns with the March 2021 Green Datacentres and Digital Connectivity: Vision and Action Plan for Scotland which sets out ambitious plans to develop Scotland's International subsea fibreoptic capacity.

Scotland is in the process of delivering world class fibre-first infrastructure across the country and in so doing, the country will be ready for the advent of technologies such as 5G, AR/AI and IoT. There is a drive to create many more data centres to support these technologies and there is widespread recognition that investment and support of these facilities is dependent on more subsea cables.

SFT, through its Host in Scotland (HiS) initiative, is focussed on attracting new international subsea fibre and datacentre infrastructure to Scotland. Discussions with industry and other public sector colleagues have highlighted the unavailability of diverse, resilient dark fibre capacity and available duct between the north of Scotland and the large centres of population in the Central Belt. In order to achieve the inclusive economic growth which could be obtained with greater access to such infrastructure, HiS wish to consider innovative mechanisms for the delivery of capacity and diversity in an economic manner.

Specifically, HiS wish to obtain data to enable a comparison of the cost, complexity and deliverability differential between a terrestrial fibre build from the North Coast of Scotland to Edinburgh and the subsea options.

FarrPoint was commissioned by SFT to work in partnership with Pioneer Consulting to deliver an analysis of the subsea telecommunications cable route options to inform this initiative. For this desk-based study, Pioneer Consulting has drawn on its subsea telecommunications cable permitting, market intelligence, and experience from carrying out numerous feasibility studies and due diligence assignments for project developers or financiers. Pioneer Consulting has also relied on some private sources of information through its extensive network of contacts across the subsea cable industry.

2.2. Approach / Method

The first task was to map the requested options for subsea fibre routes as shown in Table 2 and Figure 2, and then refine these routes with Geographical Information Systems (GIS) using the best available evidence on physical and environmental constraints.

Once the routes are finalised, the optical design can be completed and the final costs including landing points can be calculated to present a final set of costed options. This approach is presented as three stages:

- Stage 1 – initial route development;
- Stage 2 – route design;
- Stage 3 – engineering design and costings.

The initial routes proposed were as follows:

Option	RFQ Description	Requested Locations
Option #1	Direct from Celtic-Norse ➔ Inverness (Green dashed line)	Dunnet Bay & Inverness
Option #2	Direct from Celtic-Norse ➔ Edinburgh (Red dashed & solid lines)	Dunnet Bay & Cockenzie
Option #3a	Festoon from Celtic-Norse ➔ Inverness ➔ Banff ➔ Tampnet ➔ Dundee ➔ Edinburgh (Yellow dashed lines)	Dunnet Bay, Inverness, Banff, Aberdeen, Dundee & Edinburgh
Option #3b	Festoon from Celtic-Norse ➔ Banff ➔ Aberdeen ➔ Dundee ➔ Edinburgh (Yellow dashed lines)	Dunnet Bay, Banff, Aberdeen, Dundee & Edinburgh
Option #3c	Celtic-Norse ➔ Banff ➔ Aberdeen ➔ Dundee ➔ Edinburgh ➔ Newcastle (Yellow dashed lines)	Dunnet Bay, Banff, Aberdeen, Dundee, Edinburgh & Newcastle

Table 2: Requested routes from RFQ

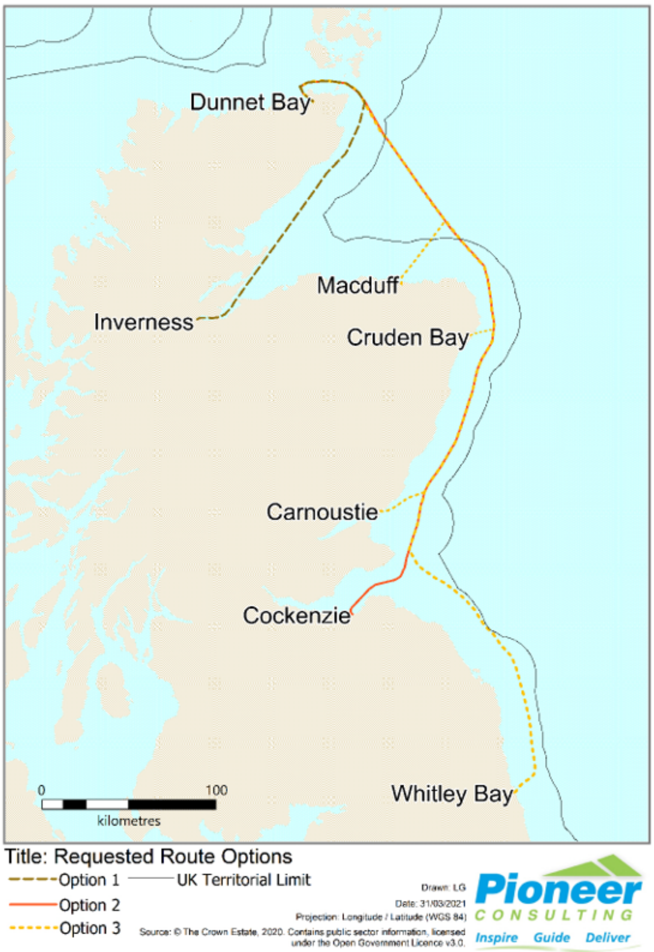


Figure 2: Requested Routes from RFQ

2.3. Limitations of Study

The best available spatial data has been used to develop the routes, and each of these datasets have their own limitations which are summarised in Appendix 3.

Only high-level cable route engineering has been carried out for this work. Additionally, the price data for cable route survey and cable installation operations has been estimated which is regarded as sufficient for this early feasibility study. Actual supply contract negotiations and agreements are likely to result in different figures. Consequently, the high-level costing provided is preliminary at this stage.

2.4. Report Structure

The remainder of this report is structured as follows:

- Section 3 presents the Stage One approach to route development. It provides a comprehensive view of the capacity and connectivity status and trends, including the current festoon system and technical solutions relevant to the current terrestrial and offshore situation. Also included in Section 3 are outcomes of discussing the requested landings with the current operators and a review of the terrestrial infrastructure which have both helped form the alternative proposed landings.
- Section 4 takes the alternative landing locations developed in Stage One forward to Stage Two, the marine route development using spatial analysis on what physical and environmental features will obstruct or constrain the cable project. It provides recommendations in taking forward the route to licensing stage and pre-application consultation.
- Section 5 provides the final step, Stage Three, advising on the engineering approach, including suitable technologies and suppliers feedback, and generating costs of the proposed routes.
- Section 6 focuses on the project management: the project risk, plan of work and build options of the proposed cable system options.
- A number of appendices complete the report as follows:
  - 1: References
  - 2: Glossary
  - 3: Data Stewardship and Recommendations
  - 4: Potential Stakeholders in Marine Site Selection
  - 5: Carbon Emission Costs

3. Stage 1: Initial Route Development

3.1. Introduction

In this section we undertake a review of similar domestic festoon systems, both in Europe and internationally, to help determine the most suitable route design for this requirement. Various festoon network designs have been developed over time as governed by specific requirements, geographical constraints, and available technology. There are several good examples from which it may be possible to ascertain some best practice and benchmarking to bring to this project.

This section also reports on our contacts with the potential landing parties to investigate the potential to partner and/or share facilities. Interest from potential partners can drive design and ultimately the cost models with respect to fronthaul and Cable Landing Station (CLS) facility costs, both of which can be expensive to build from scratch.

Given the geography and the constraints that may restrict the design of subsea cable routes, ensuring a reliable physical transmission infrastructure and high availability connectivity may require the use of some terrestrial infrastructure portions to avoid or shortcut hazardous subsea areas. It is therefore necessary to conduct an early review of existing terrestrial infrastructure to help determine the potential landing sites and provide input to the marine design options detailed in Section 4.

3.2. Review of Similar Festoon Systems

With about half of the world's population living within 200 kilometres of a coastline, a myriad of subsea cable systems has been deployed over the past decades to serve multiple coastal population centres. These coastal cable systems range from ultra-short (a few kilometres long) to cross fjords in the Nordic countries for example, to longer systems such as the 3,500 km, multi-segment Prat cable system along the Chile coast. In this report, 'festoon systems' are defined in the broad sense of domestic or regional submarine networks connecting several landing sites in a limited geographical area.

Parallel to coastlines, submarine festoon systems can be designed as linear festoons, trunk and branch networks, or ring networks connecting several population basins. Independently of this network architecture, the physical cable infrastructure may be designed using unrepeatered or repeatered technology. Unrepeatered has no active submerged equipment requiring remote powering from the landing sites while repeatered technology has submerged optical amplifiers periodically inserted along the cable to help the optical signals overcome long transmission distances between distant end points.

3.2.1. Festoon System Design

In a linear festoon configuration, all the intermediary sites are connected to the two adjacent sites with dedicated subsea links. A linear festoon configuration can be considered as a collection of point-to-point cable systems in cascade and requires two landings per intermediate sites (sites B, C or D in Figure 3 below). The thin blue lines between landing sites in Figure 3 represents the physical structure of the submarine cable that houses the optical fibre pairs shown as thick black lines. The typical number of fibre pairs may range from 4 to 16 in a repeatered cable design, and up to 96 fibre pairs in an unrepeatered design, with even more on very short distance e.g. 1,008 fibre pairs for the 3 km UEL (Ultra Express Link) cable system deployed by HKT in Hong Kong.

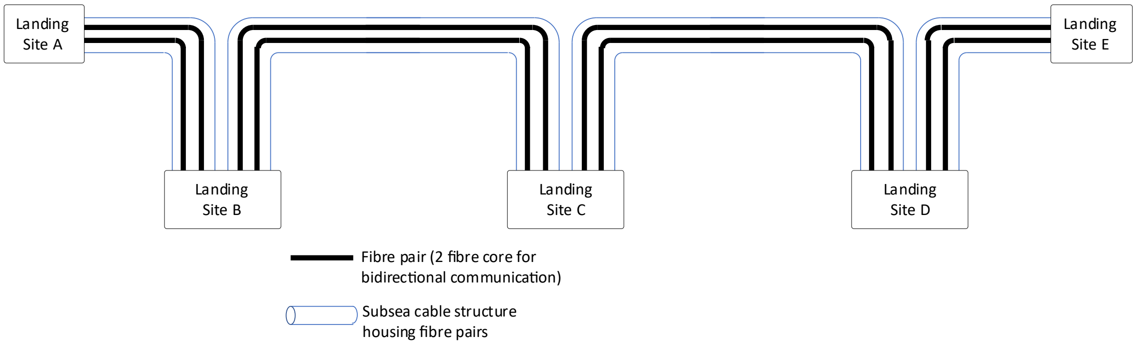


Figure 3: Linear festoon system design

Source: Pioneer Consulting

In order to maximise network availability, each of these dual landings should comprise two distinct landings with some physical separation between the subsea cables at the shore end. This puts more constraints on the project planning and implementation from regulatory, technical and project management perspectives.

Festoons are vulnerable to outage, as cable cuts in the middle of the system cause the entire network to be split into subsections with no connectivity available between the end points.

To help overcome this, a trunk and branch architecture is illustrated in Figure 4. Branches in a submarine cable system are enabled by Branching Units (BUs), which are submerged equipment that has the capability to join three cables, and therefore permit connections between more than two points. In a system designed as a trunk and branch architecture, only branches of the deep-water trunk cable approach landfall along the shallower continental shelf. Some fibre pairs in the trunk are designed as express fibres, while other fibres are routed to the intermediate landing sites via the subsea branches. Since damage is much more likely in the shallow water regions, this would only affect the landing served by a damaged branch, while the traffic carried by the express fibre pairs is unimpacted.

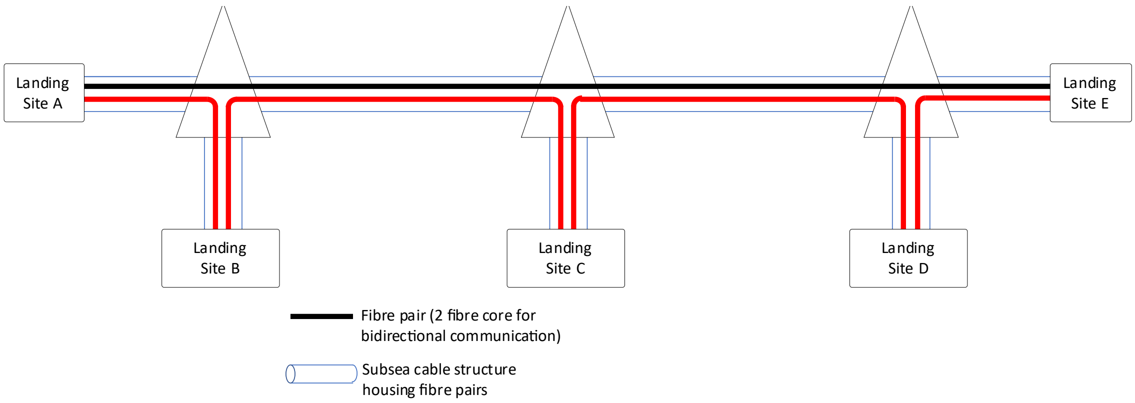


Figure 4: Linear trunk and branch system design

Source: Pioneer Consulting

In their simplest design, trunk and branch networks rely on branching units offering a fixed optical fibre routing between the trunk and the branches along the cable system. In Figure 4, one fibre pair is configured as an express fibre pair connecting the end points through the trunk. The other fibre pair is routed by the branching units in such a way that it connects all the landing sites in the cable system (such a fibre pair is often named local or omnibus fibre pair).

With more fibre pairs in the cable structure, more complex optical fibre routing can be designed to serve a variety of applications depending on traffic capacity and matrix. Figure 5 represents an example with three fibre pairs in the trunk section of the festoon system.

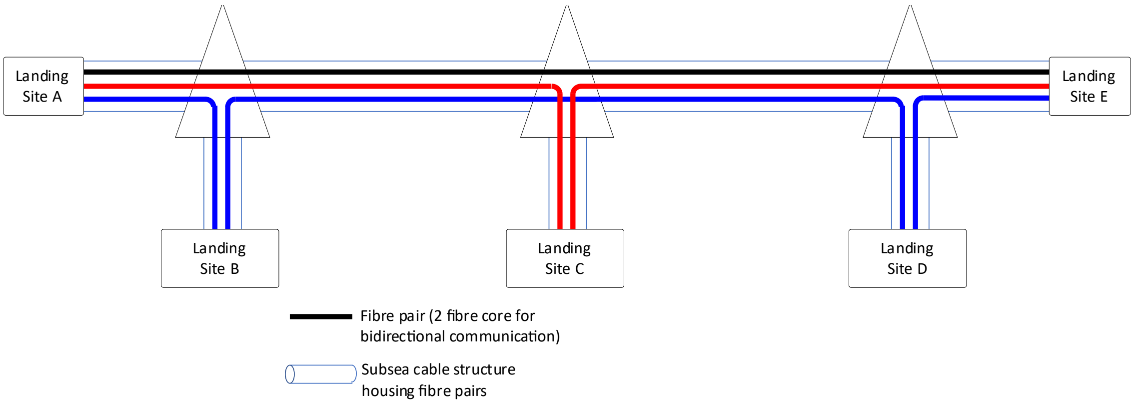


Figure 5: Linear trunk and branch system design with various fibre routing

Source: Pioneer Consulting

The black line represents an express fibre pair with direct end-to-end connectivity and lowest latency. Red and blue fibre pairs are local fibre pairs with a specific connectivity pattern between the landing sites (in Figure 5 the blue fibre pair connects Landing Sites A, B, D and E, while the red fibre pair connects Landing Sites A, C and E).

The two architectures described above leads to 'linear' network configurations which connect landing sites located along a coastline. Regional geographical features can lead to a ring architecture and some examples are provided later in Section 3.5.1. Such a ring architecture is illustrated in Figure 6 with the same dual landing arrangement at each landing site as for the linear festoon architecture.

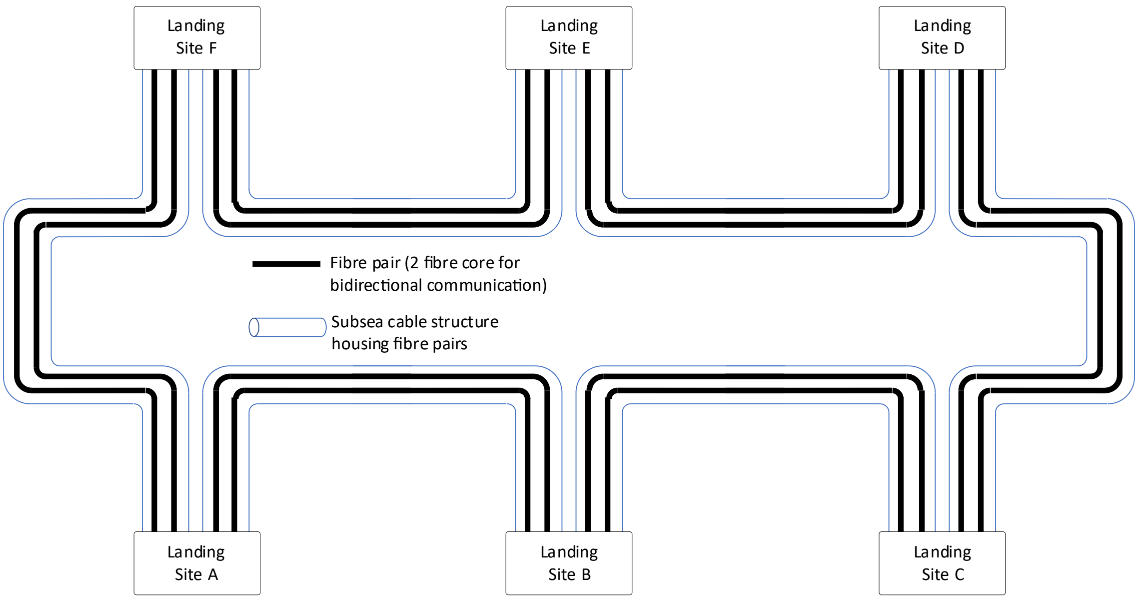


Figure 6: Ring system design with dual landings

Source: Pioneer Consulting

In the ring festoon architecture depicted in Figure 6, no single cable cut will leave any of the landing sites disconnected. For instance, if a cable cut occurs anywhere between the Landing Site B and the Landing Site C, B would still be able to talk to C by sending the optical signals in the clockwise direction around the ring (through A, F, E and D). Note that should a Landing Site no longer be able to operate (e.g., due to power outage in the Landing Site E), the protection path described above (through A, F, E and D) would no longer be available.

The trunk and branch arrangement can also be applied in the case of a ring configuration as illustrated in Figure 7. If the fibre routing is properly designed around the ring and the fibre pair count is large enough, a failure of one cable landing station does not affect the traffic between the other landing sites.

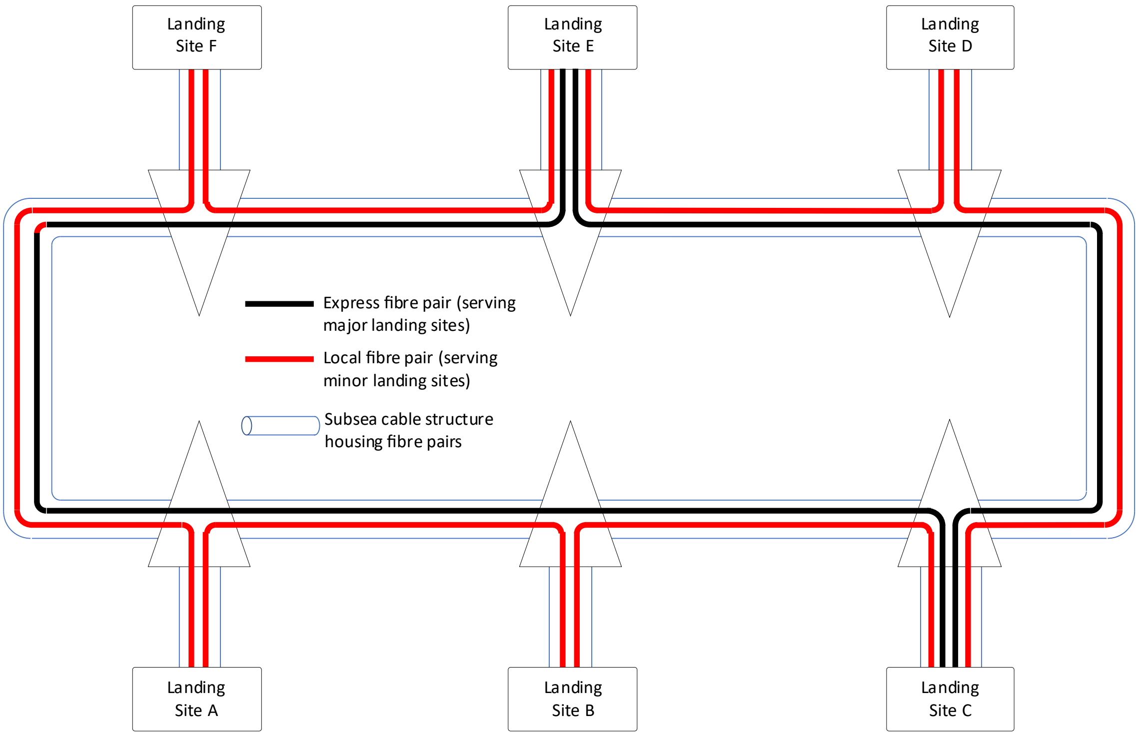


Figure 7: Ring system design with branches

Source: Pioneer Consulting

As can be seen, there are a variety of design options available to architect festoon networks aiming at serving multiple landing sites. The most appropriate choice is governed by geographical and network availability requirements.

3.3. Technical Solutions – Optical Capacity

The worldwide subsea transmission infrastructure consists of a combination of long distance, repeatered and shorter distance, unrepeatered cable systems.

3.3.1. Repeatered Cable Systems

Repeatered cable systems require optical amplifiers to be housed in sea cases which are designed to withstand water depth down to ~8,000 metres and are remotely powered from cable landing stations using high voltage Power Feed Equipment (PFE). PFE typically delivers voltage of a few kV in the case of regional cable systems and up to 15 kV for trans-oceanic cable systems. The submarine cable structure includes an electrical conductor (typically made of copper) used to transport the power to each repeater.

The optical amplification compensates for the attenuation of the optical fibre and allows the optical signals to span very long transmission distances between the end points; up to 15,000 km with a repeater spacing in the range of 70 km. Wavelength Division Multiplexing (WDM) allows many optical signals, each at a specific optical wavelength and carrying a data payload, within the gain bandwidth of optical amplifiers. Wavelength counts range from 40 to 120 depending on the data rate supported by the wavelengths and the cable system characteristics. Spatial Division Multiplexing (SDM) allows an increase in the number of fibre pairs in cable systems.

In comparison, a typical transatlantic cable system design was able to transport 130 x 100 Gbps optical signals per fibre pair in 2015 with a total of 6 fibre pairs giving a total cable capacity of 78 Tbps. More recent designs which are planned to be ready for service in 2024-2025, will offer 50 x 400 Gbps per fibre pair and a fibre count of 24 resulting in a cable capacity of 480 Tbps.

3.3.2. Unrepeatered Cable Systems

By definition, unrepeatered (aka unpowered) systems includes no active repeater element under water. This simplifies the structure and the operation of the submarine link as no high-voltage PFE is required. The presence of repeaters in long-haul cable systems leads to an upper limit on the fibre pair count due to power limitations and space constraints inside the repeater sea case: each fibre pair requires its own optical amplifier pair, which in turn requires power and space. As a result, the number of fibre pairs in an unrepeatered cable system is generally larger than in repeatered cable systems, with a typical number being 48 or 96 fibre pairs.

Submarine cable systems fitted with submerged Remote Optically Pumped Amplifiers (ROPAs), which are jointed to the cable some distance away (typically 80 to 150 km) from the cable landing station, also fall into the unrepeatered category. The rationale is that ROPAs are passive subsystems that do not require electrical power. ROPAs do need some energy to provide local optical gain when they are traversed by the optical signals: this energy is remotely provided from the cable ends via optical pumping through the fibre(s). The optical pump modules housed in Submarine Line Terminal Equipment (SLTE) act as an 'optical power feed equipment' that does not require a repeatered cable structure with a thick conductor layer offering low electrical resistance.

Because unrepeatered cable systems are loss-limited systems, there is a strong coupling between the link fibre capacity and reach performance: when one is increased, the other one is reduced. For a given optical transmission terminal configuration (and with no ROPA in the line), the current state of the art offers e.g., 12.6 Tbps over 320 km and only 300 Gbps (i.e., 0.3 Tbps) over 350 km. With ROPA inserted in the line, 12.6 Tbps and 300 Gbps can be achieved over 360 km and 400 km, respectively. By contrast, repeatered cable system capacity is far less dependent on the transmission distance.

3.4. Technical Solutions – Optical Connectivity

The simple linear festoon configuration offers by design a static optical connectivity, which forces multi-hop paths to make a 'stop and go' at each intermediate landing site. For example, in Figure 3, transmission between Landing Site A and Landing Site D will require the optical wavelengths to travel through the intermediary Landing Sites B and C.

The trunk and branch architecture described in the previous Section is based on full fibre drop at each branching unit i.e., the fibre routing between the trunk and branch paths is frozen at the time of the branching unit manufacturing/cabling and remains static over the lifetime of the cable system. More advanced branching unit functionality can be made available in the case of repeatered cable systems with branching units remotely powered from the landing sites. Figure 8 depicts the first level of optical flexibility that can be brought by branching units in a trunk and branch architecture with 1x2 optical switches built in the branching unit on a per fibre basis. Commands are sent from the Network Operating Centre (NOC) to adjust the optical switches position inside the branching unit and configure fibre pairs in trunk express or branch add/drop mode. The 1x2 optical switches provide a coarse granularity for the optical switching inside the subsea cable systems, at the fibre pair level. This provides more flexibility than the full fibre drop previously described.

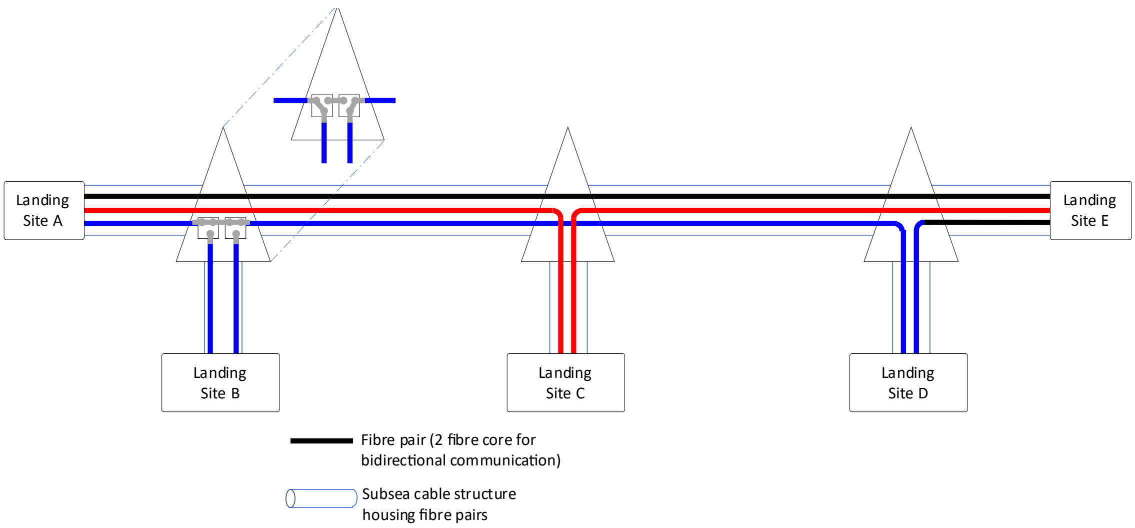


Figure 8: Flexible fibre routing via 1x2 optical switches

Source: Pioneer Consulting

Another optical switching technology with finer granularity has become available in the past two years. This is built around Reconfigurable Optical Add Drop Multiplexers (ROADM) units built in a sea case and typically deployed in a branch about three water depths away from the branching unit on the branch cable. The desire for more flexible traffic reconfigurability has led to the development of subsea-qualified ROADM technology for submarine networks. In the example illustrated in Figure 9, all the optical wavelengths transported by the blue fibre pair are directed by the branching unit facing the Landing Site D to the ROADM unit inserted in the branch connected to the Landing Site D. Driven by commands received from the NOC, the optical switches inside the ROADM unit will be adjusted to individually route the optical wavelengths either to the branch terminated in the landing Site D or back on the trunk path as dictated by the traffic connectivity requirements.

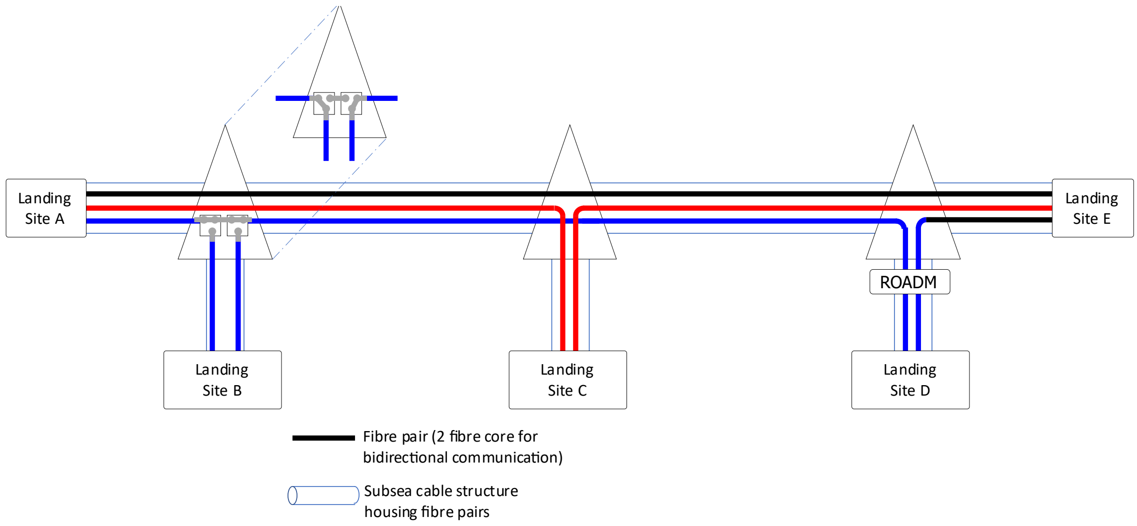


Figure 9: Flexible sub-fibre routing via ROADM unit

Source: Pioneer Consulting

The two-body arrangement allows the ROADM unit to be lifted from the seabed for repair while still leaving the branching unit and its trunk fibres unmoved and untouched. A failure of the ROADM unit in this network architecture will not affect performance of the trunk or of other branches.

Both 1x2 optical fibre switching and wavelength ROADM routing can be deployed only in repeatered cable systems that can remotely power the active switching components installed on the seabed. In unrepeatered cable systems with significantly larger intrinsic fibre pair counts, fibre pairs are typically not a scarce resource and static fibre (and wavelength) routing can generally meet connectivity requirements for multiple customers and traffic patterns at optimum cost and operational simplicity.

3.5. Current Status & Trends

Because of its simplicity and the possibility to plan a phased implementation, the linear festoon system design has often been the preferred approach to build regional networks with multiple population centres to serve. This kind of submarine cable system has often been in competition with terrestrial alternatives. For example, Italy decided not to replace a long linear festoon network along its west coast due to maintenance costs which were deemed to be higher than the operational costs of the domestic terrestrial networks. Linear festoon system architecture is still in several projects under construction like the Prat cable system along the Chile coasts. Some geographical constraints are naturally conducive to linear festoon networks with a good example being provided by the linear festoon systems along the Norwegian coasts. Linear festoon subsea cable systems represent the simplest and most cost-efficient approach to connect the small centres of population scattered along the coast.

Originally found in very long-haul cable systems (e.g., the 39,000 km SEA-ME-WE 3 cable system connecting south east Asia, Middle East, and west Europe), the trunk and branch architecture has been progressively introduced into regional festoon cable system. This trunk and branch approach can be found in cable systems with total end-to-end length in excess of 400 km.

Ring architecture for regional networks is generally imposed by the regional geography. Masses of waters like the Persian Gulf or the area between Central America and the Caribbean Islands have seen the deployment of ring festoon cable systems. Focusing on the Persian Gulf, both linear festoon with dual landing and trunk and branch architectures have been deployed, each with its own benefits and drawbacks with respect to network availability in case of cable cuts.

From a broader perspective, there is renewed interest in festoon cable systems with the development of many projects worldwide, whether in developed countries where they offer a solution to enable connectivity diversity with respect to existing terrestrial optical fibre infrastructure or to get around a challenging geography, or in emerging regions where deploying a subsea communication infrastructure is faster and less expensive than building terrestrial networks.

3.5.1. Review of Selected Examples

An example of a linear festoon system is the Brazilian Domestic Festoon System that went live in 1996. This cable network is represented in Figure 10 with 13 unrepeatered legs and 14 cable landing stations over a length of 2,500 km along the Atlantic coast of Brazil.

Figure 10: Brazilian festoon system (2,543 km total length, in commercial service since 1996)

Source: TeleGeography

Unlike the linear festoon system along the west coast of Italy that was decommissioned in the 2010s, this cable system is still active today after 25 years of commercial operation. It is, however, unclear whether any Brazilian operator is planning to replace it with a more recent network or whether the Italian scenario will repeat with the traffic switching from the submarine infrastructure to existing terrestrial links when the submarine festoon network is phased out. Provided the submarine legs do not experience too many failures requiring cable repairs and introduction of additional attenuation, unrepeatered legs can be upgraded to offer higher capacity by simply introducing the latest transmission equipment technology in the landing sites. In the case of relatively short transmission distances between two adjacent landing sites (e.g., not more than 200 km), conventional and very cost-effective transmission equipment as used in terrestrial backbone networks can be used to increase the festoon cable capacity over time.

Although the example provided in Figure 10 dates from 1996, more recent regional or domestic cable systems have been designed and built with a linear festoon architecture. Figure 11 represents a 1,004 km linear festoon network along the Norwegian coast that was put in commercial service in 2007 between Trondheim and Narvik.

Figure 11: Polar Circle Cable (1,004 km total length, in commercial service since 2007)

Source: TeleGeography

Polar Circle Cable was built and is operated by KystTele (established in April 2005) with the objective to connect Trondheim with Northern Norway where overproduction of clean energy and a competitive power price is expected to lead to the development of hyper scale data centres in the region.

The coastal geography obviously makes Norway a good candidate for costal submarine networks. Norway continues to develop such infrastructure such as in Figure 12 with N0r5ke Viking festoon system currently under construction and planned to be ready for commercial service at the end of 2021.

Figure 12: N0r5ke Viking (810 km total length, in construction, planned to be ready for service at end of 2021)

Source: TeleGeography

The length of the legs between two adjacent land sites is short enough in the two Norwegian examples to enable the use of simple transmission technology. However, some optical routing functionality can be implemented in cable landing stations so that the traffic between, e.g., the Landing Site D and the Landing Site F is passed through in the optical domain in the Landing Site E. By doing this, express optical path can be offered which requires less transmission equipment in the intermediate landing sites but higher-end transmission equipment at each extremity of the optical path due to the longer total transmission distance to be spanned with no intermediate signal regeneration.

Linear festoon subsea networks can deviate from the linear configuration if imposed by the regional geography. Figure 13 shows the architecture of the Converge ICT Domestic Submarine Cable system in the Philippines with a mixture of single, dual, and triple landings at the landing sites. Each landing site is connected to other landing site(s) with unrepeatered legs. In the centre of the network shown in Figure 13, terrestrial links can be assumed to interconnect the landing sites located on the same island in order to close the network and form some loops for maximizing network resiliency.

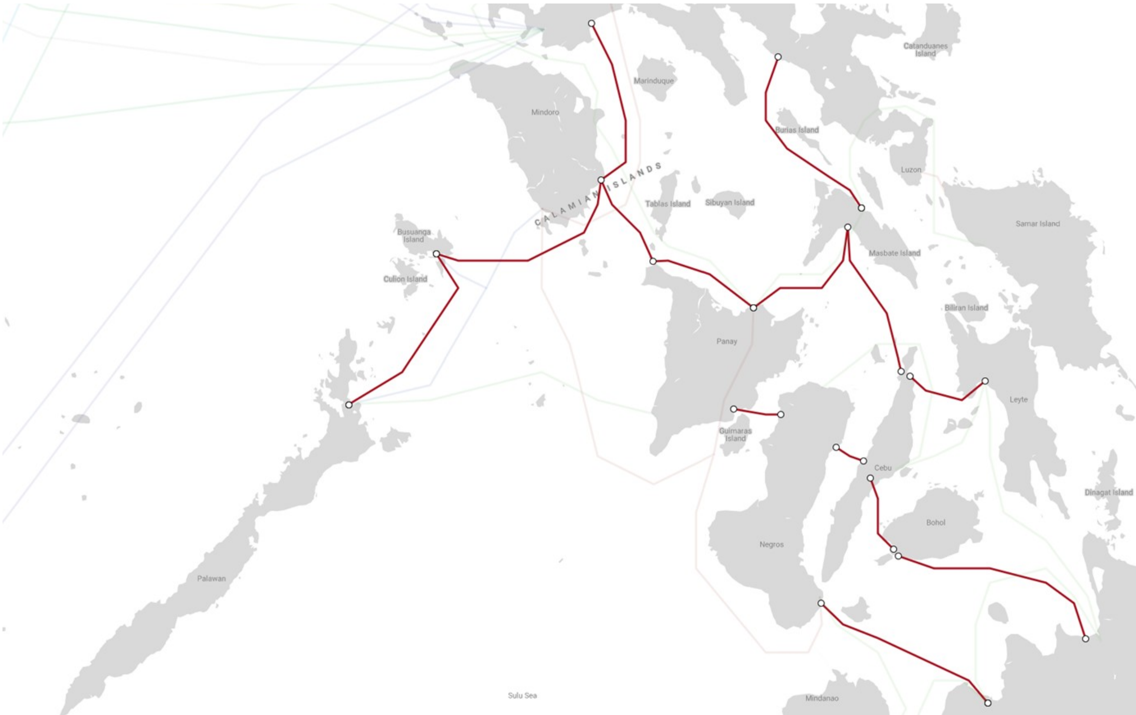


Figure 13: Converge ICT Domestic Submarine Cable, Philippines (1,300 km total length, in construction, planned to be ready for service at end of 2021)

Source: TeleGeography

When the average length between adjacent landing sites exceeds 150 to 200 km and/or when there is a need to enable express traffic between major destinations without going through intermediate sites, a trunk and branch festoon architecture is often used instead of a linear festoon. A good example of such an application is provided by the Confluence-1 cable system developed by Confluence Networks and planned to be ready for service in 2023 (see Figure 14). The Confluence-1 value proposition is to offer direct, reliable, low-latency undersea connections among major cable landings on the East Coast of the USA.

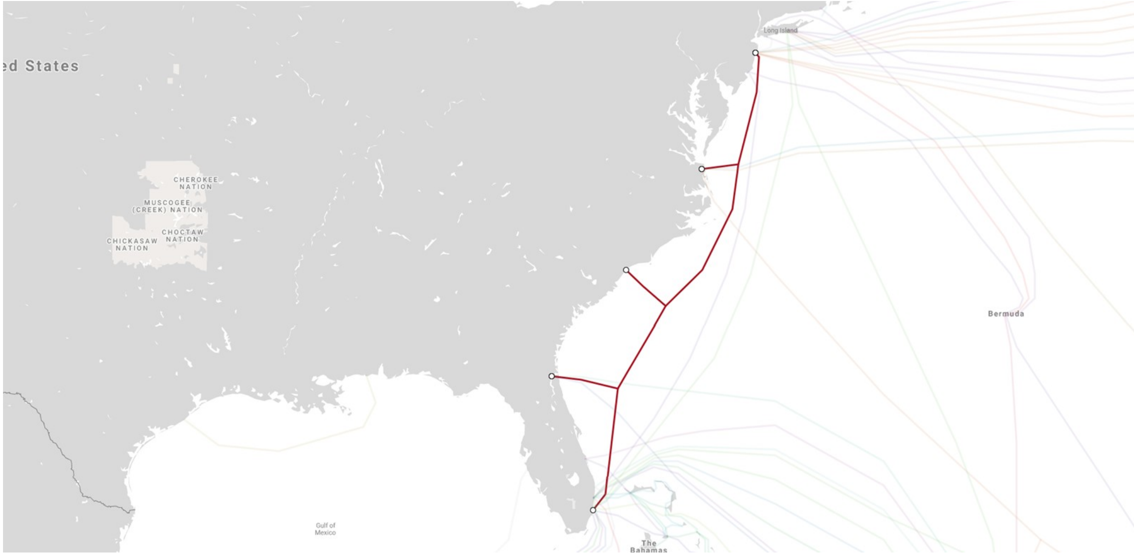


Figure 14: Confluence-1 trunk and branch festoon network (2,571 km total length, in development, planned to be ready for service in 2023)

Source: TeleGeography

The Confluence-1 selling points are based on the understanding that terrestrial networks do not follow a path as optimum and straight as submarine cables on the sea bed which leads to higher latency, and that terrestrial cables are more prone to frequent cuts than their submarine counterparts.

Trunk and branch festoon architecture can take more complex forms than the simple one represented in Figure 14. An example of more complex topology is provided by Figure 15 depicting the Kumul Domestic Submarine Cable System in Papua New Guinea.

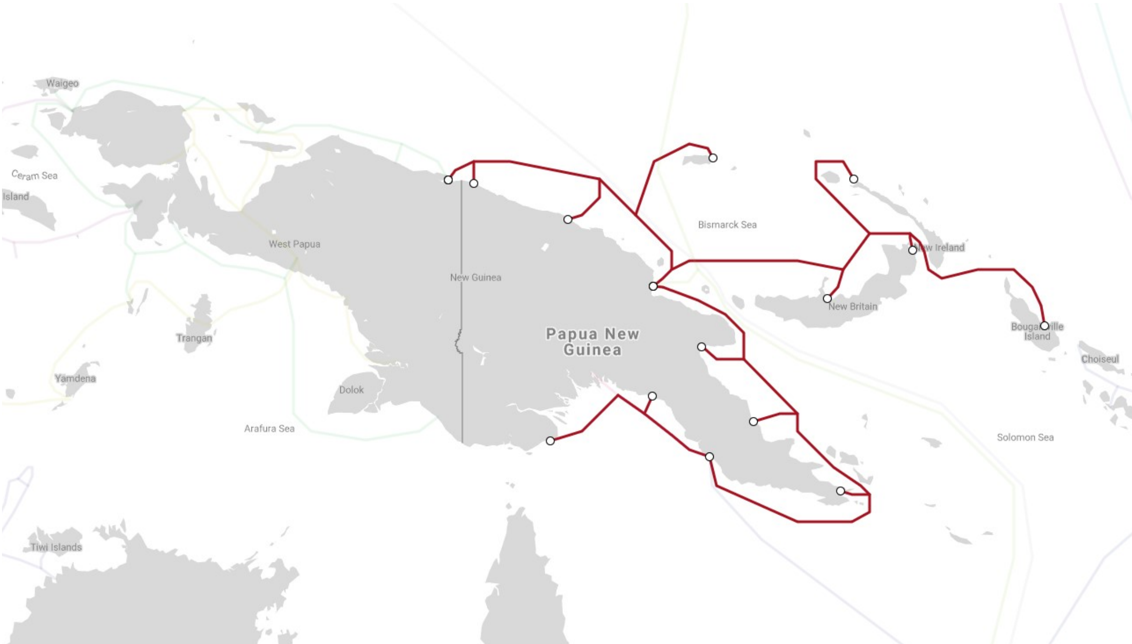


Figure 15: Kumul Domestic Submarine Cable System (5,457 km total length, in commercial service since 2019)

Source: TeleGeography

Moving to ring system design, the Persian Gulf provides a good example to illustrate the diversity and the evolution of the approaches that can be followed to connect the Gulf countries. Subsea cable systems in the Persian Gulf were built 25 years ago as simple point-to-point systems or using the linear trunk and branch configuration as depicted in Figure 16.

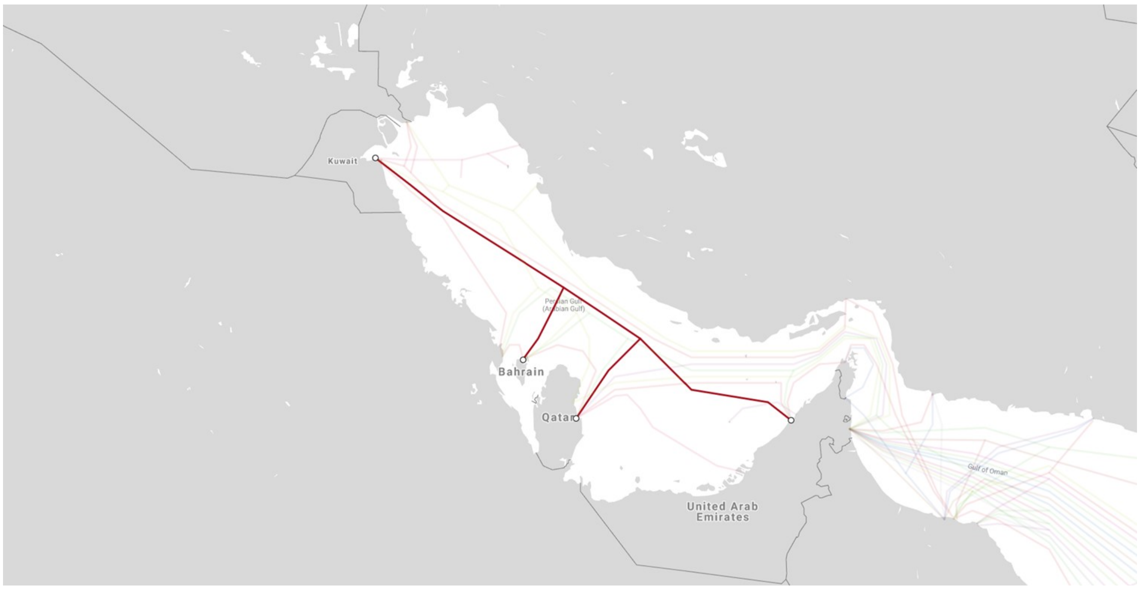


Figure 16: Fiber Optic Gulf – FOG (1,300 km total length, in commercial service since 1998)

Source: TeleGeography

Ten years later, FLAG Telecom (now GCX) built a ring system design with dual landings between Oman and Kuwait (see Figure 17).

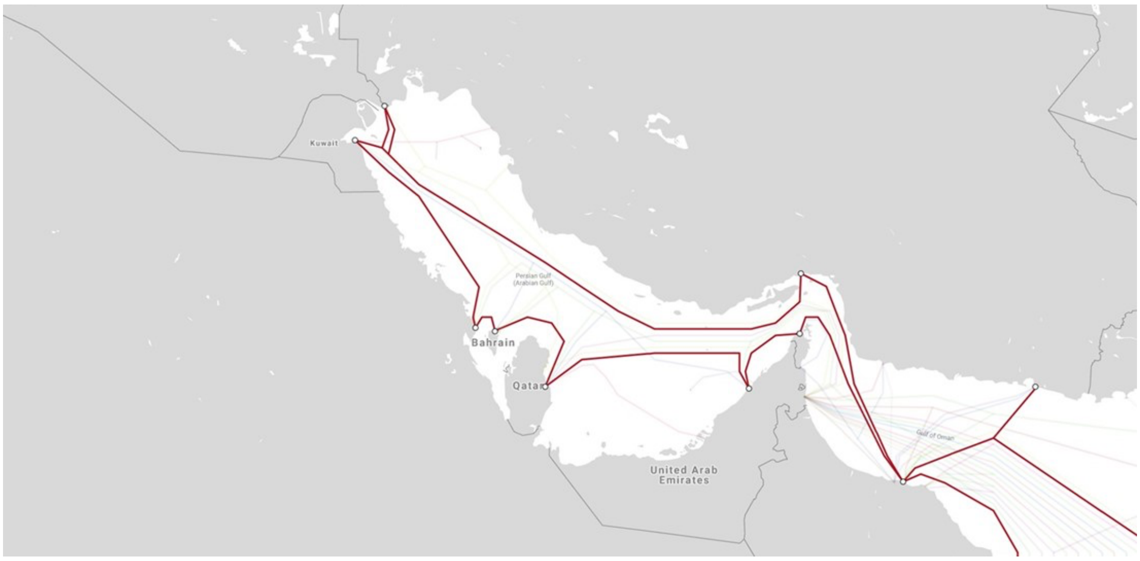


Figure 17: FALCON Persian Gulf ring (about 3,400 km total length, in commercial service since 2006)

Source: TeleGeography

In 2012, Gulf Bridge International (GBI) put their Gulf loop into service which was based on a trunk and branch design as illustrated in Figure 18.

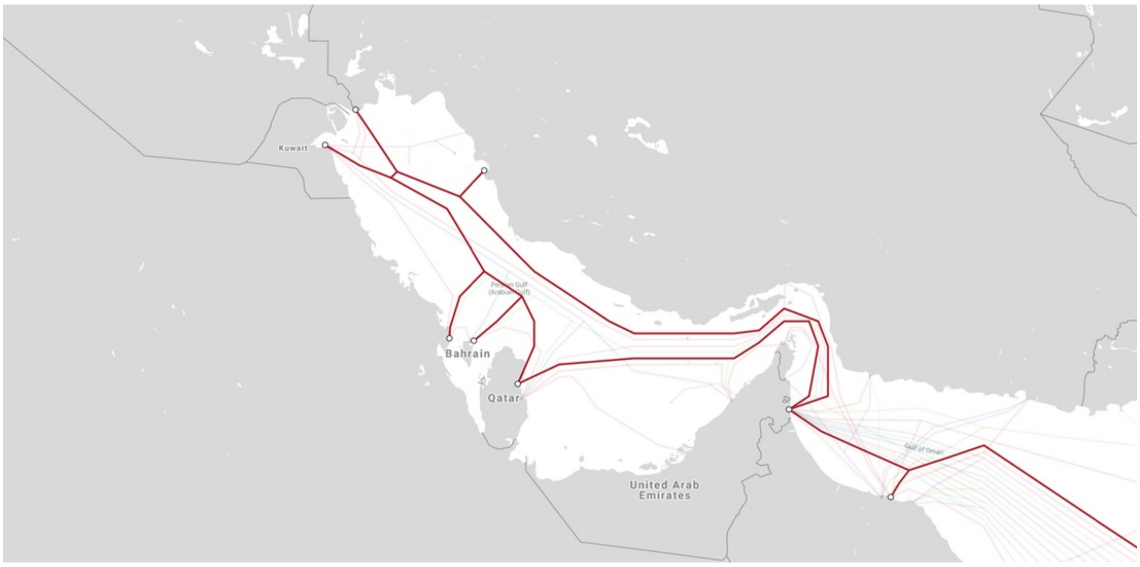


Figure 18: GBI Gulf loop (about 2,800 km total length, in commercial service since 2012)

Source: TeleGeography

A ring network with a festoon configuration (dual landing per landing site) and a mix of unrepeatered and repeatered legs totalling 8,600 km was deployed in the Caribbean Sea in 2001. This Americas Region Caribbean Ring System (ARCOS) network is shown in Figure 19 below.

Figure 19: ARCOS (8,600 km total length, in commercial service since 2001)

Source: TeleGeography

3.6. Discussions with Potential Landing Partners

In addition to initial route planning, discussions were held with potential landing partners as their involvement can also affect the design options.

There are a number of existing submarine cable landings on Scotland's North-Eastern coastline and, given one of the drivers for looking at the potential feasibility of a domestic festoon system is the lack of available, diverse terrestrial backhaul, it would make sense to investigate at a high-level the possibilities of sharing infrastructure e.g. beach manhole, fronthaul, cable landing stations space etc. This could potentially provide the dual benefits of lower infrastructure costs and additional interconnectivity options to increase diversity.

A similar investigation was made into potentially sharing infrastructure with the two new, trans-North Sea cables which land near Newcastle. As a consequence, the following four landings were identified for investigation:

- SHEFA-2 at Banff;
- Tampnet at Cruden Bay near Aberdeen;
- NO-UK at Seaton Sluice near Newcastle;
- Havhingsten at Whitley Bay near Newcastle.

3.6.1. SHEFA-2

The SHEFA-2 (SHEtland-FAroes) cable system, deployed in 2008, connects Torshavn in the Faroe Islands to Banff on mainland Scotland, with intermediate stops at Maywick and Sandwick in Shetland and Ayre Of Cara in Orkney. SHEFA-2 is an unrepeatered, 3 fibre-pair design. The cable is owned and operated by Shefa, a subsidiary of Faroese Telecom. A diagram of the system is shown in Figure 20.

Figure 20: SHEFA-2 cable system

Source: TeleGeography

In February 2021, Pioneer approached the management of Shefa regarding potentially sharing any common infrastructure that may be available for use. In general, Shefa were very keen to explore the possibility of collocating with a second submarine cable, although the scope for sharing infrastructure is somewhat limited as, while they do own their own BMH, the fronthaul duct and CLS space is leased from BT Openreach.

Given the third-party leasing of the CLS and terrestrial ducts by SHEFA-2, the opportunity for cost saving here is somewhat reduced. That said, it is understood that there are three different duct owners in Banff, all of which seem to pass <500m from the SHEFA-2 BMH, so the potential for diverse backhaul routing exists at this landing site.

3.6.2. Tampnet

The Tampnet Offshore fibre network shown in Figure 21 connects the mainland of Scotland (Cruden Bay, north of Aberdeen), England (Lowestoft) and three landings in Norway (Farsund, Kårstø and Øygarden) and predominantly serves the oil and gas industry in the North Sea.

Figure 21: Tampnet OffShore

Source: TeleGeography

In February 2021, Pioneer approached the International Carrier Management of Tampnet to explore the possibility of sharing any common infrastructure that may be available for use. As with Shefa, Tampnet were open to possible collaboration regarding housing a new submarine cable landing.

Tampnet's CLS, located ~2km from Cruden Bay, has sufficient free space and available power to accommodate terminal equipment for an additional submarine cable. Furthermore, Tampnet own an existing, 2 km long PLSE (pre-laid shore-end), containing 12 FPs, which is currently unused. The condition and age of the PLSE is unknown. The duct from the BMH to the CLS is also owned by Tampnet.

It is understood that there are two terrestrial duct providers available at the Tampnet CLS.

3.6.3. Havhingston

The Havhingston cable system connects Newcastle to Houstrup, Denmark and lands on the English east coast as Whitley Bay. Given the mini-consortium ownership structure of this cable system it would be complicated, if even possible to easily negotiate any agreement to share infrastructure.

Following discussions with Aqua Comms and subsequent investigation, it is our understanding that landing additional cables to this beach whilst observing ICPC separation recommendations, would not be possible. More detailed research would be needed to further understand the exact situation, but it is believed that a combination of the Blyth Demo windfarm and existing submarine cables have exhausted the available usable seabed.

3.6.4. NO-UK

The spatial analysis that followed the initial investigations at the Havhingston landing concluded that there was insufficient seabed to install an additional cable in the NO-UK BMH, therefore no further investigation was undertaken at this juncture.

3.7. Review of Existing Terrestrial Infrastructure

A common issue with new submarine cables system once they land, is the lack of diverse terrestrial backhaul routes for onwards connectivity. Constructing new backhaul routes for submarine cables is often prohibitively expensive for several reasons, chief among those is that fact that the 'easiest' route(s) have already been used. Secondly, because submarine cables tend to land in remote areas which by their nature have a lack of existing infrastructure to build along i.e. roads or rail, any new build will generally be 'green-field' in nature.

There is a lack of diversity in both availability of suppliers and physical separation of backhaul routes in the north of Scotland. Often initially overlooked, this can form a high barrier to entry for many new submarine systems and can often be detrimental to a business case predicated upon the assumption that building the marine portion of a cable system is the expensive or hardest part of a project.

At this point it should be noted that the network maps used in this section are based on a mix of publicly available, proprietary, and commercially sensitive information. As such, it may render part of this report unsuitable for open-source publishing, and also may contain some historically older sources which may be out of date or incorrect. However, this does not change the overall premise that for much of Scotland's coastal areas out-with the central belt, backhaul options for new submarine cables are limited.

3.7.1. Thurso / Dunnet Bay

Using publicly available information, it appears that Dunnet Bay is served by a single BT Openreach duct which terminates some 5-10 km further north at Dunnet Head.

Aside from the lack of route diversity this situation brings, it is commercially disadvantageous to be geographically reliant upon a single supplier. There may be other duct suppliers in the area (SSE or Vodafone), but these details are not available to assess.

3.7.2. Inverness / Moray Firth Area

This coast would appear to be slightly better served with at least two different duct providers having infrastructure running around the coast east of Inverness, passing the landing points of both the Caithness Moray HVDC cable at Buckie and SHEFA-2 at Banff. While having options for alternate duct suppliers does provide the opportunity for route diversity, care should be taken to ascertain how much physical diversity actually exists between different supplier’s duct networks. They may well be in the same or adjacent duct or trench, or simply on opposite sides of the road.

3.7.3. Dundee

As with much of Scotland outside of the Central Belt, options here are limited once you get away from the central part of Dundee city. For a submarine cable landing other than new build, the options would seem to be limited to BT Openreach.

3.7.4. Cockenzie (Edinburgh)

Situated near several major roads and less than 15 km from the boundary of The City of Edinburgh, this is the proposed site of a potential new data centra and the area is well served with options for diverse backhaul. Both BT Openreach and Zayo have duct infrastructure close by (<1 km away) and it is understood that other operators are also in the area. Securing a new, diverse backhaul path from this site should be readily achievable.

3.7.5. Cambois (Newcastle)

No publicly available information was available at the time of writing this report, but it is understood that there is available duct running alongside the A189, which is approximately 1 km from a possible landing site on Cambois beach. The duct route continues along the A19 and directly passes alongside the Stellium Datacentre located in Cobalt Park. Securing a new, diverse backhaul path from this site should be readily achievable.

3.8. List of Possible Landing Sites

Possible landing sites are shown in Figure 22. Aerial imagery is particularly helpful in examining the suitability of the seabed for burial and has been used to inform route development. The physical / environmental constraints at these landing sites are discussed in further detail in Section 4.6.

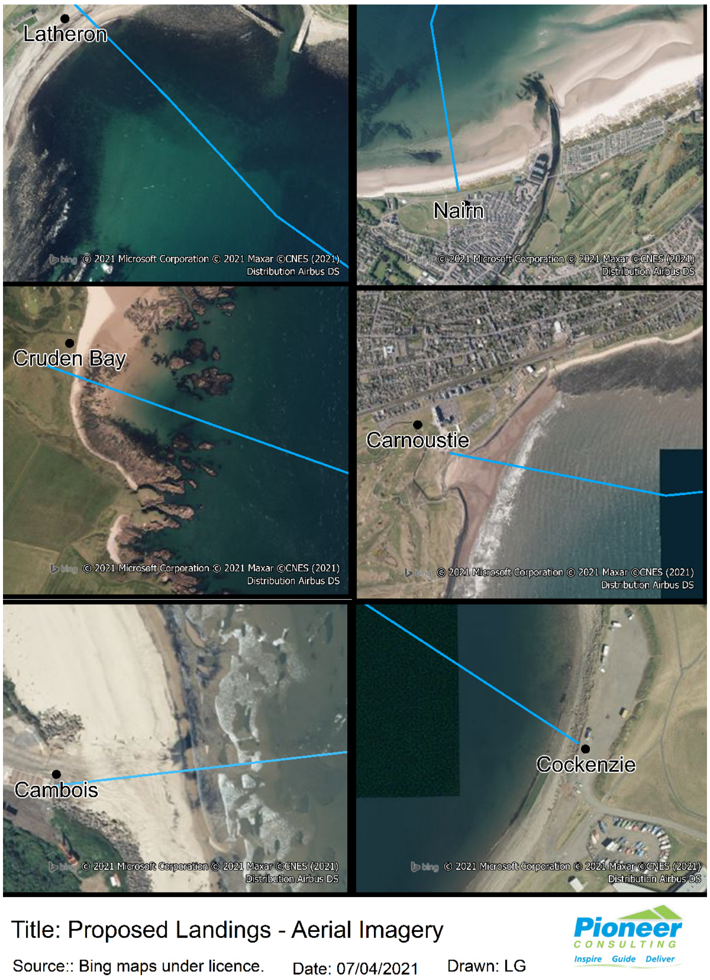


Figure 22: Aerial Imagery of Proposed Landing Sites

4. Stage 2: Design

4.1. Introduction

This stage assesses the potential high-level route designs as follows:

- Assessment of whether a pure dark-fibre system or a mix of fibre and repeaters would provide the optimal trade-offs;
- Identification of any constraints, specifically:
  - Transmission technology, i.e. options of numbers of fibre pairs and repeatered / unrepeatered
  - Route planning i.e. seabed assessment, landing feasibility and competing infrastructure
  - Marine planning i.e. permitting, environmental, fishing, other seabed user concerns etc
  - Route engineering to select cable types;
- Discussion with a selected number of systems suppliers to obtain latest pricing, technology updates and understand manufacturing lead-times;
- Generate Risk profile for all options;
- Look at high-level schedules for procurement and installation;
- Develop additional detail on end-to-end costings for all options;
- Conduct high-level assessment of available marine assets, obtained by approaching appropriate industry contacts;
- Analysis on different models for both procurement and installation including turn-key vs disaggregated.

4.2. Identification of Marine Constraints

Cable installation is licensable under Part 4 of the Marine (Scotland) Act 2010 (MSA) and Part 4 of the Marine and Coastal Access Act 2009 (MCAA). Should the majority of cable be undertaken in the Scottish Inshore Region (0-12 NM) or the Scottish Offshore Region (12-200 NM), Scottish Ministers are the licensing authority and the Marine Scotland Licensing Operations Team (MSLOT) issue licences on their behalf. However, as part of the proposed cable is in English waters, a Marine Licence will also be required by the Marine Management Organisation (MMO), established under the MCAA. Both marine licence applications (MLA) should be supported by an Environmental Appraisal (EA).

All phases of a cable project (survey, installation, maintenance and decommissioning) would need to be considered in an EA as part of the marine licensing regime, and the content and approach of an EA serves as useful guidance in the route development process.

Understanding the natural and anthropogenic constraints placed on subsea cable developments is key to developing the site selection process. Constraints to cable survey and installation activities may be environmental (e.g. unsuitable ground, such as rock or hard clay), physical (e.g. obstructions such as windfarms), political (e.g. area use conflicts with fishing), legislative (e.g. nature conservation protected areas), or they may be economical (e.g. crossings with cables and pipelines may be too high).

Using spatial data for site selection is a powerful tool for the handling and integration of a wide range of marine activities referring to environmental and technical factors that can influence the location of potential development. Scotland and England have advanced platforms for marine spatial data, e.g.

- NMPi [https://marinescotland.atkinsgeospatial.com/nmpi/];
- MIS[https://defra.maps.arcgis.com/apps/webappviewer/index.html?id=3dc94e81a22e41a6ace0bd327af4f346].

It is helpful to rank the marine constraints during route development into simple categories to aid interpretation:

- Hard constraints are generally physical obstructions that would restrict cable development;
- Soft constraints are advisory features and could lead to additional legal requirements or studies that would add cost and delay to a project.

4.3. Hard constraints

4.3.1. Rock

Cables should be buried to target depths and rock should always be avoided. The JNCC in collaboration with BGS created UKSeaMap in 2010 which was used to extract rock features. With reference to Figure 23, the requested route goes through a significant rock seabed in the Pentland Firth. Additionally, the Pentland Firth has one of the strongest tidal currents in the world, and this together with rock seabed makes this section an extremely undesirable environment for a submarine cable. The alternative proposed route avoids these environments by starting at Latheron to continue south to Inverness. This alternative does require the availability of a suitable terrestrial solution from Dunnet Bay to Latheron.

Recommendation - The starting point (Dunnet Bay) of the requested route requires routing through a marine area which is extremely undesirable; therefore an alternative route, Option #1, has been proposed with a starting location of Latheron.

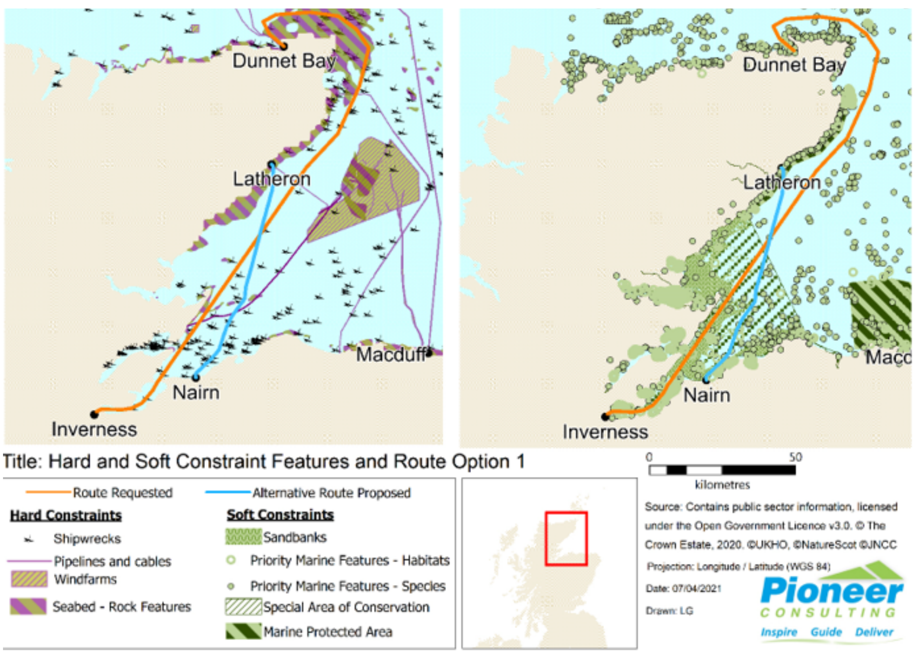


Figure 23: Option #1 hard & soft constraints

4.3.2. Shipwrecks

Shipwrecks not only present a physical obstruction to cable installation, but their significance or contribution to cultural heritage are also legislative reasons for avoidance. The Protection of Wrecks Act 1973 is used to protect wrecks of historical, archaeological, or artistic importance. The Ancient Monuments and Archaeological Areas Act 1979, provides protection of monuments of national importance, most commonly land based. The Protection of Military Remains Act 1986 affords the protection of military wrecks, a designation imposed by the Ministry of Defence (MoD).

For an EA, it is likely that both a Written Scheme of Investigation and a Protocol for Archaeological Discoveries will be required. The WSI is based on an archaeological assessment of marine geophysical, geotechnical and landfall survey data and early consultation with Historic Environment Scotland and English Heritage is recommended to ensure the marine route survey outputs are appropriate. The potential risks to historic assets will be mitigated through the use of site-specific Archaeological Exclusion Zones, which specify the extent of each exclusion zone so as to avoid all known and potential cultural heritage receptors. AEZs will apply to any activities that may disturb the seabed, within which all development-related activities will be prohibited. Their locations and extent will be agreed with curatorial authorities in advance. The extent of the AEZ is based not only on the perceived archaeological potential of the asset, but also on its extent, if known. The radius of each AEZ has been designed to encompass all debris / structure visible on the seabed, with an added dimension to adequately protect both potentially buried remains and the potential for mobile debris associated with the direction (and extent) of the scour. Without knowing the exact AEZ for all the wrecks in this desk-based study, the route options have avoided 500 m on either side of all wrecks.

Recommendation: Early commissioning of an archaeologist to inform survey design is advised.

4.3.3. Renewable Energy Infrastructure

Scotland supports a thriving renewable energy industry and Crown Estate Scotland (CES) and The Crown Estate have allocated seabed space, which may or may not have infrastructure in place, as shown in Figure 23 - Figure 27. Opportunities to coexist are limited given the potential for cable maintenance, and the vessel movement requirements extending to a potential 1km buffer. The data used in this project is lease areas and may over-estimate the scale of seabed usage. The Caithness to Moray route option overlaps slightly with the Beatrice windfarm lease area but does not necessarily mean the cable coincides with infrastructure; only consultation with the operator can determine the exact route to be taken.

Recommendation: Where a 1km buffer distance has not been applied to renewable energy infrastructure (i.e. with Beatrice windfarm in Moray), early consultation is required on potential for coexistence.

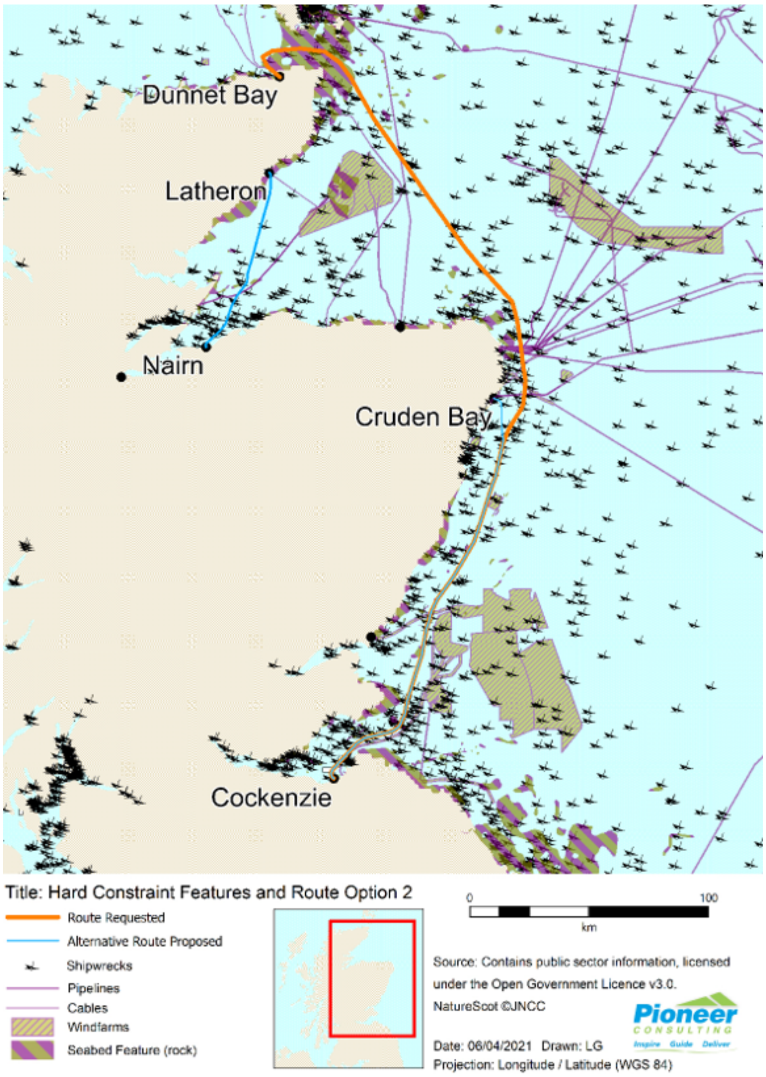


Figure 24: Option #2 hard constraints

4.3.4. Oil and Gas Infrastructure

Oil and Gas UK (OGUK) recommend a 250 m buffer on either side of the centre line of a pipeline, otherwise some form of Crossing or Proximity Agreement will be required before installing a telecoms cable. Nigg, located north of Cruden Bay in Aberdeenshire, is of critical importance to Scotland for landing oil and gas from offshore production fields. As shown in Figure 23, the requested route overlaps with twelve pipelines at Nigg: this would require extensive concrete mattressing which would likely be unacceptable to both the fishing and the licensing authority. As an alternative to avoid these pipelines, Option #1 crosses one pipeline in the Moray Firth and Option #2 (Figure 24) and Option #3 (Figure 27, Figure 26 and Figure 27), which avoids the twelve pipelines north of Cruden Bay) do not cross any additional pipelines.

Recommendation: Early consultation with oil and gas operators to determine allowable distances between uses with potential for further route development.

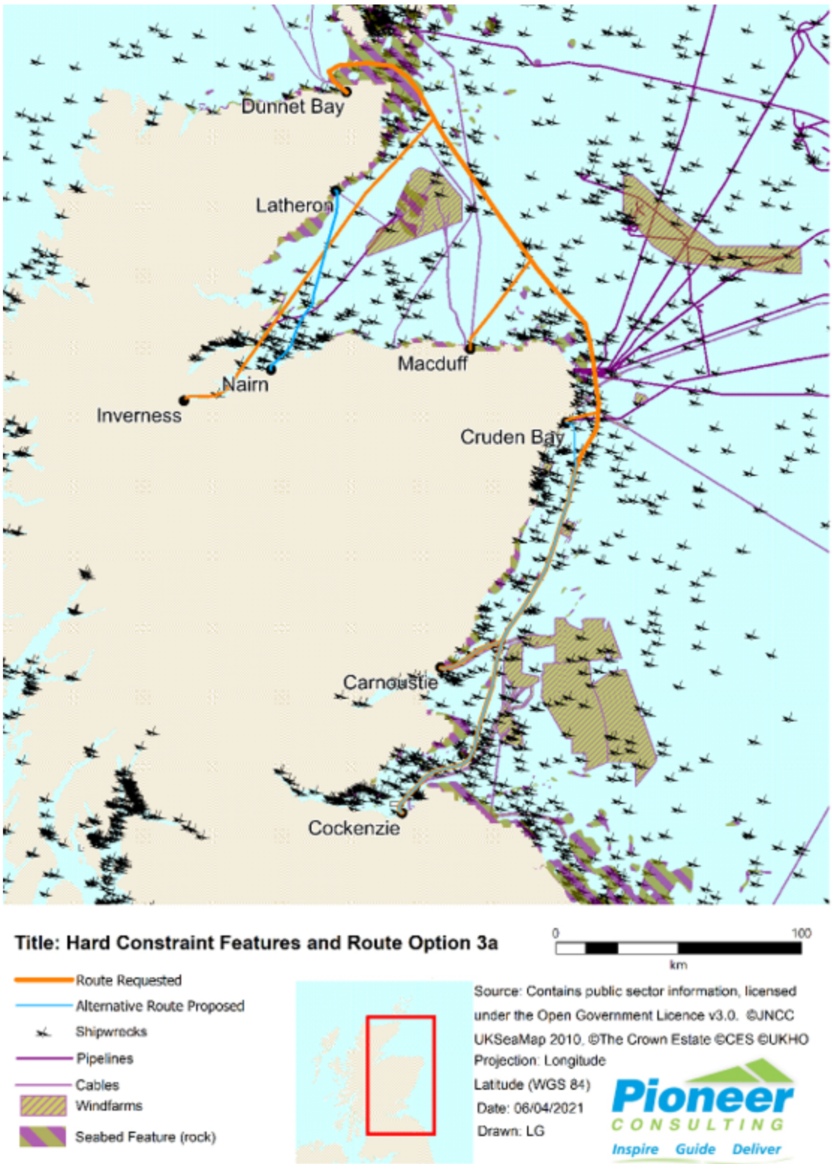


Figure 25: Option #3a hard constraints

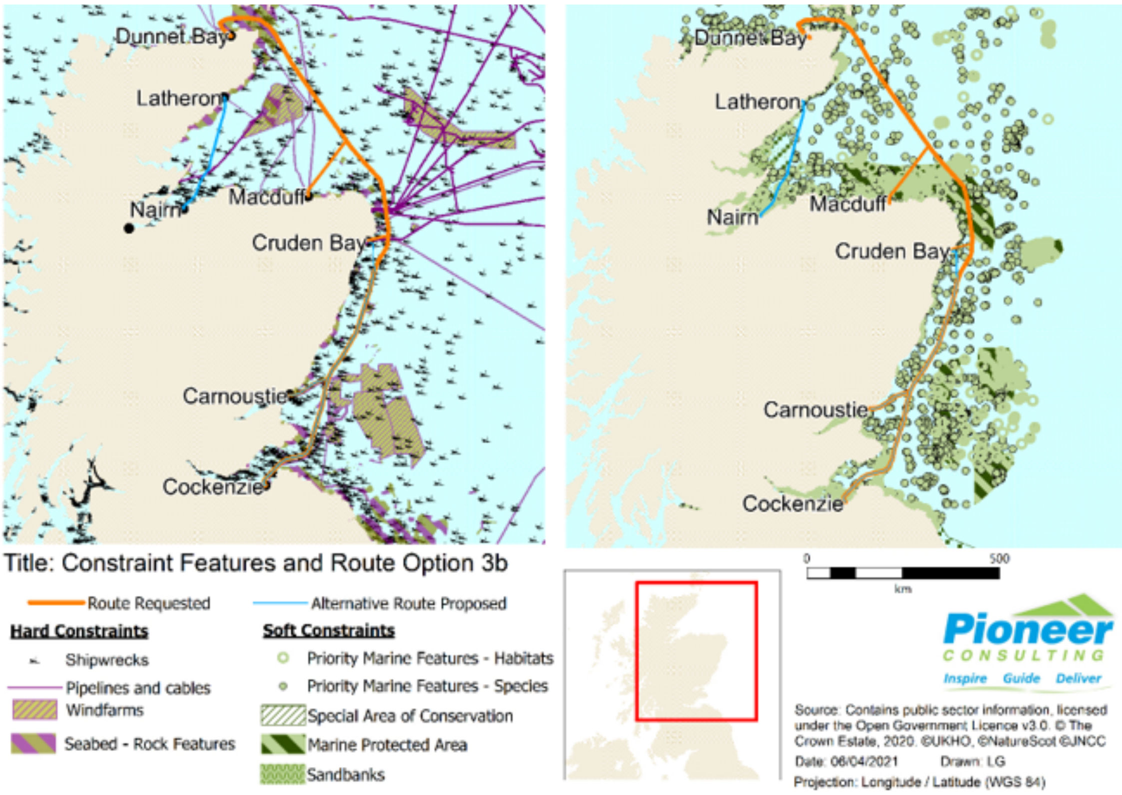


Figure 26: Option #3b hard & soft constraints

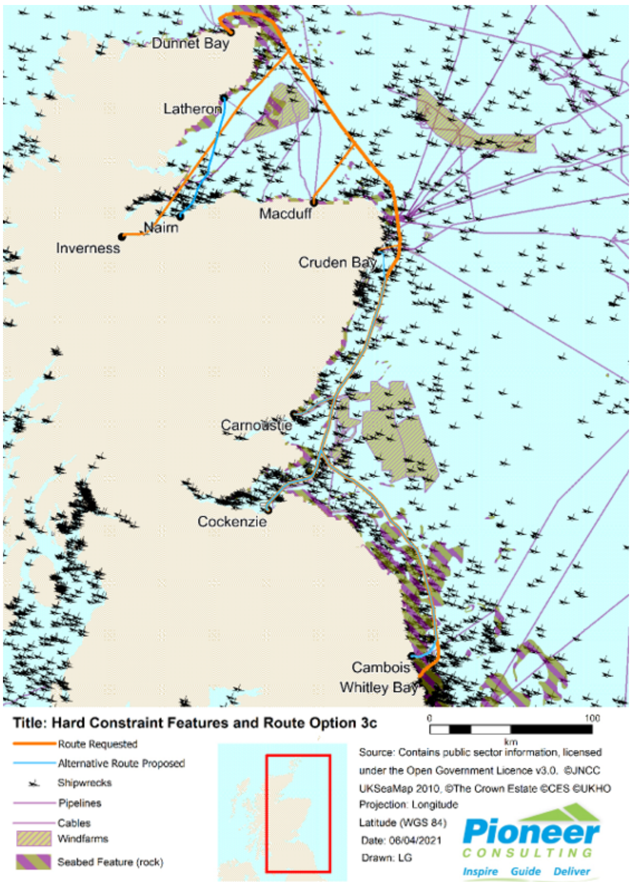


Figure 27: Option #3c hard constraints

4.3.5. Electricity and Telecommunications Cables

ICPC Recommendation 11B states that, where in service cables parallel one another, the distance between them should be maintained at 3 times depth of water where possible. However, it is recognised that these separation distances may not be achievable in all circumstances when planning a cable and so the distances may be reduced. With the use of modern navigational equipment and lay/repair practices, these distances could be reduced to 2 times depth of water after consultation and agreement by all affected parties. In areas of high cable congestion, even a separation of 2 times water depth may not be achievable.

The regulatory framework surrounding ICPC Recommendation #6 is based upon current UK practices. It is the consideration of the Guidelines that no proximity agreement is required where the minimum approach of planned subsea development and planned/existing subsea infrastructure exceeds one nautical mile (1NM) (1.852 km). However, at a separation of approximately 1NM, it is considered good practice that high-level consultation is undertaken thereby ensuring that all stakeholders are aware of each other's activities and requirements. The requested route overlaps with three cables at Caithness, and two cables north of Cruden Bay. The alternative proposed route from Latheron to Nairn only crosses one cable and avoids the cables at the north of Cruden Bay. Crossings are unavoidable going south: there is one cable south to Cockenzie, and two cables south towards Whitley Bay and so crossings should be determined after consultation and agreement with all affected parties.

Recommendation: Early consultation with other cable owners to determine crossing agreement between uses.

4.4. Soft Constraints

4.4.1. Sandbanks

Sandbanks were extracted from the UKSeaMap dataset. It is possible to achieve cable burial on sandbanks, but they may require more careful planning as installation needs to take place at certain angles in relation to the height of the sandbank formations. Sandbanks are unavoidable at the Nairn landing and affect all options as shown in Figure 23. A wider corridor may need to be surveyed followed by careful route development to ensure target burial depths can be achieved.

Recommendation: A wider survey corridor (800m) should be considered at the Nairn landing given the presence of sandbanks.

4.4.2. Other Sea Users

Under the Marine Scotland Act (2010), it is a legal requirement to consider the impacts of offshore development on other legitimate users of the sea, and this includes safety and navigation, fishing, recreation and tourism, aggregates, and military defence.

4.4.3. Marine Traffic and Maritime Safety

An EA for cable installation will likely have to consider IMO ship routing measures (including traffic separation schemes and inshore traffic zones), in accordance with The International Regulations for Preventing Collisions at Sea 1972, COLREGS.

Recommendation: Early consultation with the Marine Licensing Operations Team (MSLOT) is advised on the scale of Navigation Risk Assessment that would be required. Should there be a requirement, early consultation with the MCA is recommended on the type and timescales of AIS data to purchase and analyse.

4.4.4. Commercial Fishing

Representation of fishing activity in an EA needs to take account of the spatial and temporal variability in fishing effort and practices. The most reliable source of the distribution of fishing activity by larger vessels (over 12 m length) is based on Vessel Monitoring System (VMS). The Marine Management Organisation (MMO) applies weights and values to the VMS pings so that a more accurate picture can be obtained on actual fishing activity and is essentially a filter to remove vessels streaming to and from ports. The MMO provide this VMS-based data in Geographical Information Systems (GIS) format to sub-rectangle level for the entire United Kingdom Continental Shelf (UKCS) which provides very high-resolution data (they are 1/200th of an ICES rectangle at 3 x 1.75 nm) and allow good reporting for small areas. This information has been used in Figure 28 to report on statistics on the effort (time) to represent the most productive and economically important areas and has also separated the fisheries statistics into only mobile gear with contact on the seabed, as this sector is principally in conflict with cables, either through presenting a snagging risk and/or damaging the asset. The annual data has been amalgamated across a five-year history (as recommended by IEEM, 2010).

It should be noted however that vessels of under 10 m in length make up the majority of the Scottish fishing fleet (70 per cent) and operate principally static gear in inshore waters. Environmental baselines for inshore fishing activities in Scotland to date, at a site-specific level, are severely lacking in places and are of varying quality in terms of resolution, source, and completeness. ScotMap provides spatial data to the nearest 5 nautical miles, but this is considered too broadscale for determining the impacts from a cable project.

The desk-based study has kept route options outside 6 nautical miles (nm) as far as possible in order to avoid static gear fisheries.

Recommendation: It is considered best practice to consult with a fishermen's association early on in the project to determine what vessels would be impacted, and how to ensure the route is clear for survey without causing damage to static fishing gear.

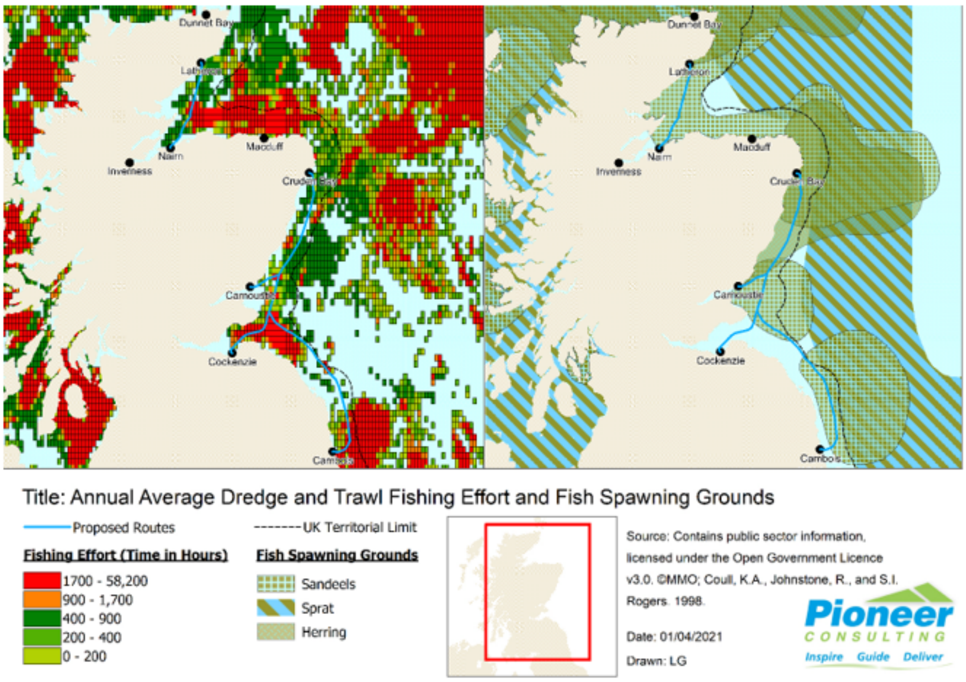


Figure 28: Commercial fishing activity

4.4.5. Recreation and Tourism Activities

Scotland's marine recreation and tourism industry has the potential to make an economic contribution to over £0.5 billion by 2025 (Scottish Tourism Alliance, 2020). Varying buffer distances to avoid interaction will apply, depending on the activity. Sports such as surfing, windsurfing, sailing, sailboat / yacht racing and rowing have large spatial requirements that would conflict with vessel activity, and therefore require larger buffers such as 500 m; sports will little spatial requirements such as kayaking, climbing, coasteering, scuba diving and angling have limited spatial conflict with cable projects. A spatial query on NMPI suggests no overlap with nearshore recreation, however it is recognised that not all recreation has been mapped. Early consultation with users through a scoping process is required in order to avoid objections at marine licence application stage.

Recommendation: It is considered best practice to consult with RYA and other bodies early on in the project (prior to marine route survey) to determine what yacht routes would be impacted at various times of the year.

4.4.6. Military and Aggregate Use

There are no military practice areas and no offshore aggregate areas for capital or maintenance overlapping with the cable routes proposed.

4.4.7. Nature Conservation

There is no automatic exclusion of any economic activities in and around the Natura 2000 network and other conservation protection areas. Instead, human activities need to comply with the provisions outlined in Article 6 of the Habitats Directive (EC Directive 92/43/EEC) to ensure that these activities are in line with the conservation objectives of Natura 2000 sites (EC, 2012). The Habitats Directive is transposed into UK law through the Conservation of Habitats and Species Regulations 2017, which covers the onshore area and up to 12 nm out to sea. Similarly, the Conservation of Offshore Marine Habitats and Species Regulations 2017 transposes the Habitats Directive into UK law for the protection of the marine environment from 12 nm out to the UK EEZ boundary (200 nm). These regulations provide designation for the conservation and protection of Special Protection Areas (SPAs) for wild birds and their habitats and Special Areas of Conservation (SACs) for habitats and species other than birds. These areas are known as Natura 2000 sites and are shown in Figure 23 to Figure 31.

Cable survey and installation activities are carried out in many Natura 2000 sites, and the management of those activities are dependent on factors of sensitivity of species or habitat, and ecological status of the site. Should the cable route traverse or come in close proximity to a Natura site, the Marine Licencing authority will have a regulatory duty to carry out an Appropriate Assessment, and the onus will be on the developer to carry out a Habitats Regulations Assessment if a project has the potential to have an adverse effect on the integrity and features of a Natura 2000 site. This study could take the form of a Marine Mammal Risk Assessment for an EPS Licence for the geophysical survey campaign, or it could be an additional study requirement at marine licence application stage.

Internationally designated sites in the vicinity of the route options are shown in Table 5 which summarise the Natura sites which are relevant to the site selection process of this desk-top study. Given the lack of sensitivity, Special Protected Areas have been excluded from the desk-based study. There may be a situation where installation or survey vessel operations within an SPA could disturb rafting or foraging birds, but this can usually be mitigated through a condition on the licence to control and reduce vessel speeds.

Recommendation: Overlap with designated sites are unavoidable. Commissioning of a Marine Mammal Risk Assessment and application for an EPS Licence prior to marine route survey will be required.

Natura Site	Qualifying Interest Features	Route Option and consequence
Firth of Forth Banks Complex MPA	Ocean quahog aggregations (Low or limited mobility species); Offshore subtidal sands and gravels (Habitat); Shelf Banks and Mounds (Large scale feature); and Moraines representative of the Wee Bankie Key (Geodiversity Area)	Proposed routes avoid this site. No further assessment is likely.
Turbot Bank MPA	Sandeels	Proposed routes avoid this site. No further assessment is likely.
Southern Trench (pMPA)	Minke whale, burrowed mud, fronts, shelf deeps.	Proposed routes avoid this site. No further assessment is likely.
East Caithness Cliffs MPA	Black guillemot	Overlap - HRA is likely, but bird surveys are unlikely given lack of sensitivity.
Noss Head MPA	Horse mussel beds	Proposed routes avoid this site. No further assessment is likely.
Buchan Ness to Collieston SAC	1230 Vegetated sea cliffs of the Atlantic and Baltic Coasts	Proposed routes avoid this site. No further assessment is likely.
East Caithness Cliffs SAC	1230 Vegetated sea cliffs of the Atlantic and Baltic Coasts	Proposed routes avoid this site. No further assessment is likely.
Conon IslandsSAC	Saltmarsh	Proposed routes avoid this site. No further assessment is likely.
Sands of Forvie SAC	Sand dunes	Proposed routes avoid this site. No further assessment is likely.
Firth of Tay and Eden Estuary SAC	1365 Harbour seal (Phoca vitulina) 1110 Sandbanks which are slightly covered by sea water all the time 1140 Mudflats and sandflats not covered by seawater at low tide	Proposed routes avoid this site. No further assessment is likely.
Berwickshire and North Northumberland Coast SAC	1140 Mudflats and sandflats not covered by seawater at low tide 1160 Large shallow inlets and bays 1170 Reefs 8330 Submerged or partially submerged sea caves 1364 Grey seal (Halichoerus grypus)	Proposed routes avoid this site. No further assessment is likely.
Lower River Spey - Spey Bay SAC	Stoney banks on Cullbin Bar	Proposed routes avoid this site. No further assessment is likely.
Moray Firth SAC	1349 Bottlenose dolphin (Tursiops truncatus) 1110 Sandbanks which are slightly covered by sea water all the time	Overlap - further assessment is likely through a Marine Mammal Risk Assessment prior to survey. Sandbanks will require careful route development and a wider corridor may need to be surveyed.
Berriedale and Langwell Waters SAC	1106 Atlantic salmon (Salmo salar)	Proposed routes in close proximity to site. Potential barrier effect to migration during installation.
Dornoch Firth and Morrich More SAC	1110 Sandbanks which are slightly covered by sea water all the time 1170 Reefs 1365 Harbour seal (Phoca vitulina) 1355 Otter (Lutra lutra) Coastal features, including, but not limited to:	Proposed routes avoid this site. No further assessment is likely.

Natura Site	Qualifying Interest Features	Route Option and consequence
	1140 Mudflats and sandflats not covered by seawater at low tide	
Culbin Bar SAC	Coastal features, including, but not limited to: 2110 Embryonic shifting dunes	Proposed routes avoid this site. No further assessment is likely.
Isle of May SAC	1170 Reefs 1364 Grey seal Halichoerus grypus	Proposed routes avoid this site. No further assessment is likely.

Table 3: Internationally designated sites in the vicinity of the Route Options

All phases of a cable project can impact sedentary seabed species and habitats as well as mobile species, including migratory routes of birds, fish and cetaceans in different ways and should consequently be dealt with differently in any Environmental Assessment. Whilst NatureScot provide spatial data on seabed species and habitats (GEMS), shown as Priority Marine Features (species and habitats in all Figures), maps showing routes of migratory birds, fish and cetaceans are a key knowledge gap for marine planning in Scotland.

4.4.8. Priority Marine Features - Seabed Species and Habitats

Priority Marine Features are shown in Figure 23 to Figure 31. Seabed impact zones will vary depending on source and pathway, and generally increased suspended sediment concentrations as a result of plough burials will be localised and therefore will have a small geographical impact range. This impact range, combined with knowledge of the type of protected feature and their sensitivity, and the levels of contaminants in the sediment, will determine the compatibility levels and risk-based decisions in line with the relevant legal framework. On this basis, and based on marine licence precedence, in order to maximise potential routing, an avoidance buffer of 500m was applied to the route selection.

Recommendation: Incorporating recommended desk-based evidence and taking seabed samples from survey will ensure impacts to seabed-dependent species are properly considered.

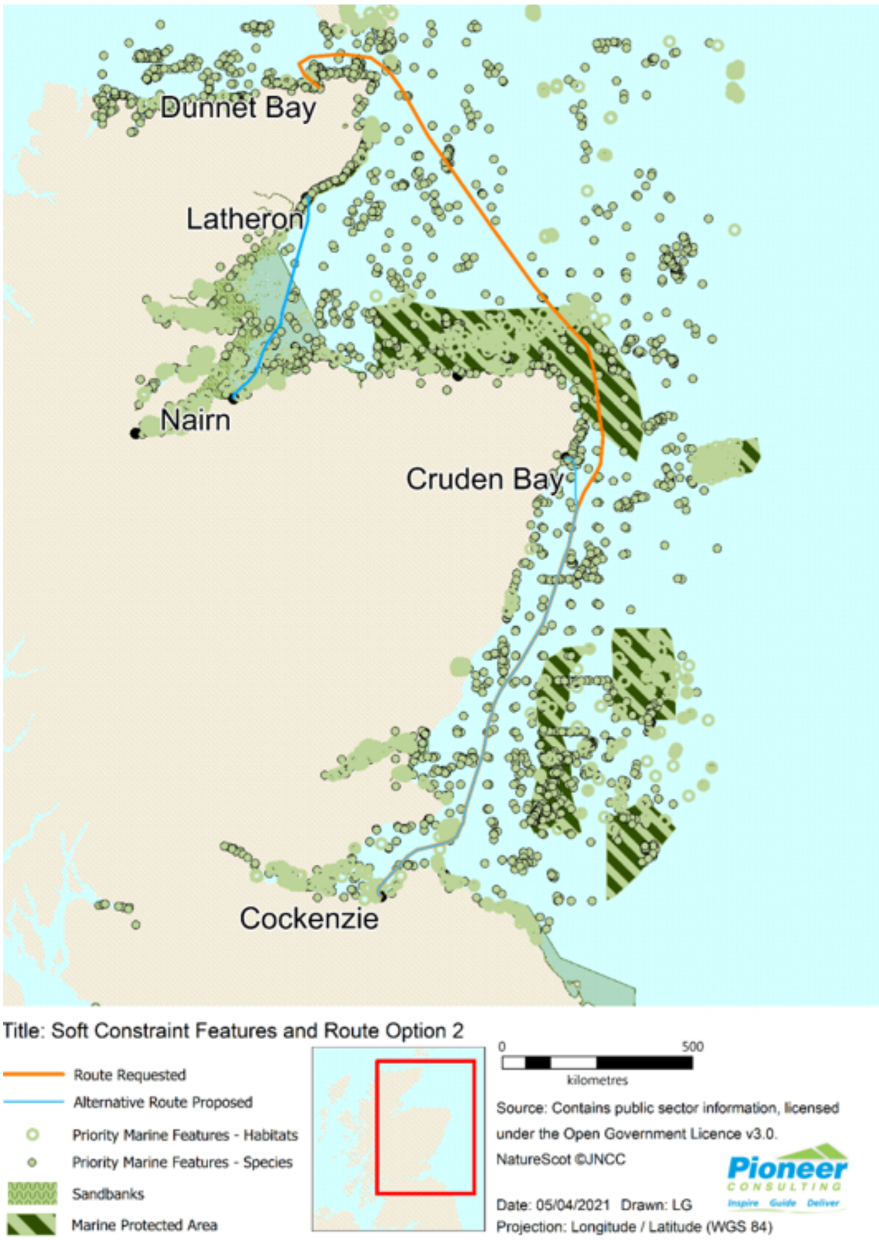


Figure 29: Route #2 soft constraints

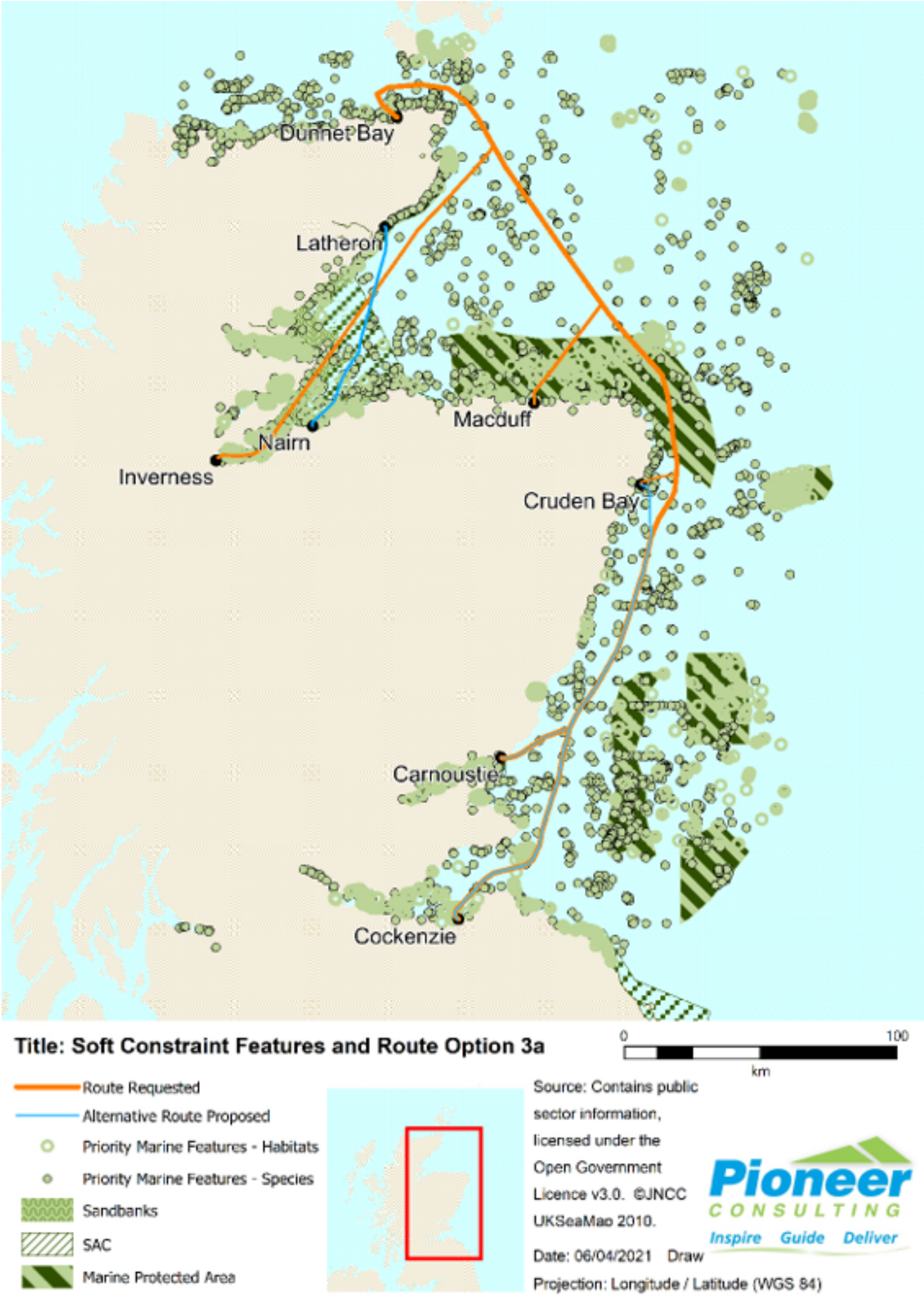


Figure 30: Route #3a soft constraints

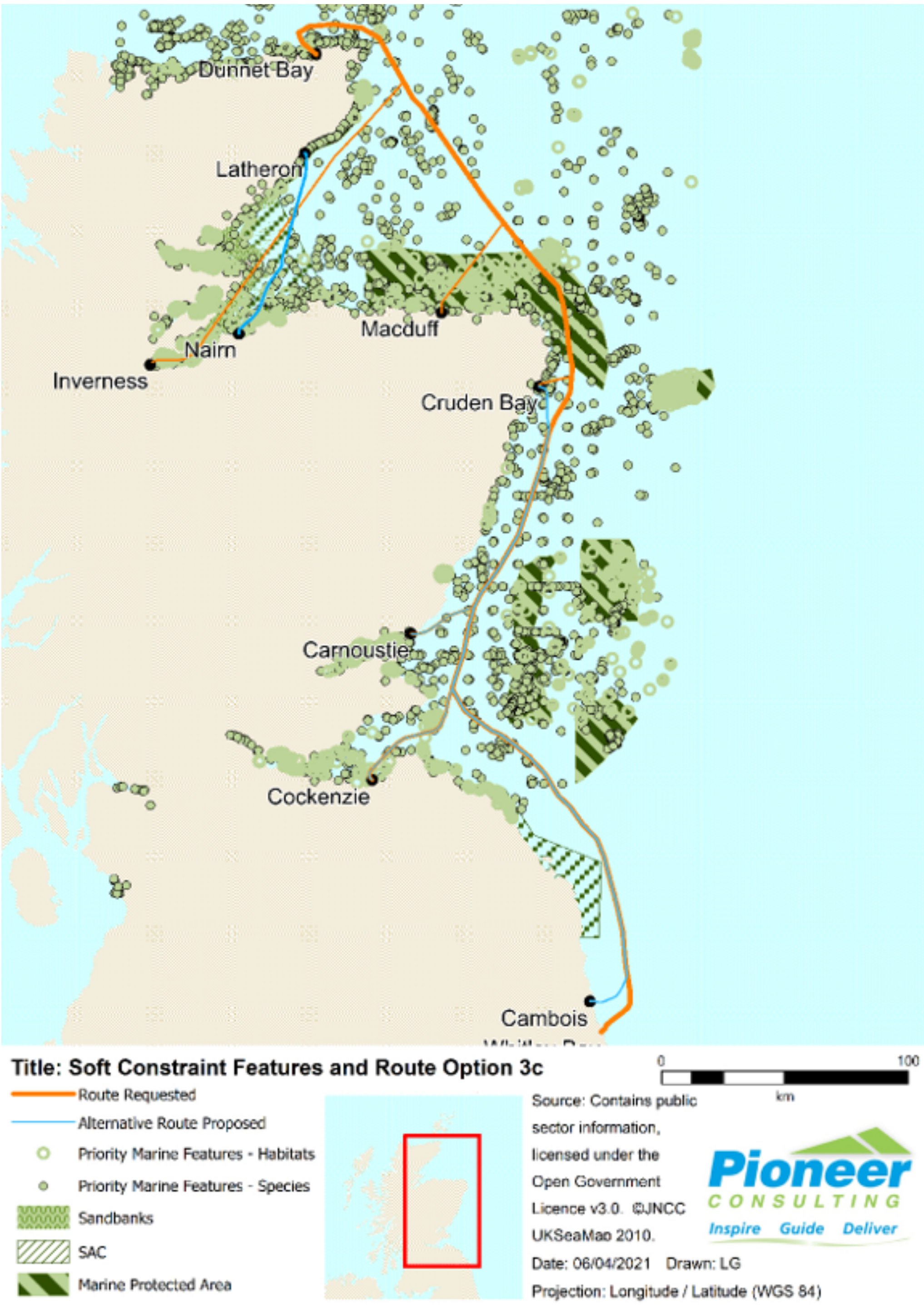


Figure 31: Route #3c soft constraints

4.4.9. Essential Fish Habitat

Fish species, which are seabed dependent for all or some of their life cycles, may be more susceptible to negative effects of disturbance to the seabed caused by cable installation. Certain species of fish spawn on the seabed and these grounds are critical habitats for commercial species. Figure 28 demonstrates the distribution of spawning grounds for three species: herring, sandeel, and sprat. These have been selected based on their sensitivity to cable installation impacts in that they are seabed-dependent species.

Given the overlap of spawning areas with all route options, it is likely that an EA on Fish Ecology will be required. Limitations of the data which is too broad scale, therefore representing very large areas, can limit the potential to adequately consider impacts from a cable project in EA. Better data from the ICES programme of international herring larval surveys in the North Sea should be used for any EA of a final route. Given the importance of the North Sea to fishing, the authorities will likely recommend retaining sediment samples taken for the marine route survey for the purpose of particle size analysis (PSA) as this information can be used to further inform the suitability of seabed substrates as sandeel habitat and herring spawning habitat.

Recommendation: Incorporating recommended desk-based evidence and retaining seabed samples from survey will ensure impacts to seabed-dependent species are properly considered.

4.4.10. Diadromous Fish

Although there is not a map of migratory salmon, trout, and European eel routes on the Scottish Planning Portal (NMPi), most significant populations are found on the North and East coasts of Scotland (Malcolm et al, 2010). The installation phase of the Latheron to Nairn route which is in all proposed options could present a barrier to diadromous fish migration which is an internationally designated site for Atlantic salmon (Berriedale and Langwell Waters SAC). Further assessment is likely through consideration in a Fish Ecology EA chapter. Given the temporary nature of installation, mitigation is likely to restrict installation during migratory sensitive times (October - November). Early consultation with users through a scoping process is required in order to avoid objections at marine licence application stage.

Recommendation: Early consultation with the Scottish Government Freshwater Lab is advised at Scoping stage (prior to marine route survey) to determine what species would be impacted at various times of the year.

4.4.11. Cetaceans

Although there is not a map of migratory porpoise, whale, and dolphin routes on the Scottish Planning Portal (NMPi), most significant migratory routes are found on the Moray coast, which is an internationally designated site for Bottlenose dolphin (Moray Firth SAC). The requested route option follows around the coast of Moray and Aberdeenshire, which is a well-known migratory route for cetaceans although unmapped and undesignated. By onshore routing from Nairn to Cruden Bay, the alternative proposed route avoids this sensitive area. Cetaceans are particularly sensitive to acoustic noise impacts emitted by survey equipment, and therefore an EPS Licence to disturb marine mammals will be required. As part of this, a Marine Mammal Risk Assessment prior to survey will be required.

Recommendation - Early engagement with MSLOT is advised prior to survey to determine EPS Licence requirements.

4.5. High Level Route Engineering

The previous section proposed a re-design of the requested routes based on the marine constraints. This section addresses the physical components of this submarine telecommunication infrastructure, including submarine cables and landing sites.

4.5.1. Cable Types

Submarine cables protect the fibre and provide mechanical strength for deployment and recovery, and protection against external aggression. Depending on the design, the cable can also provide electrical functionality to power in-line repeaters and send commands to reconfigure power switchable branching units and optical switches, and to allow cable detection and cable monitoring.

The key requirements are to provide a dry, stress-free, mechanically stable, and thermally stable environment for the low-loss optical transmission fibre, a low resistance conductor to power the undersea equipment in repeatered systems, and the robustness to allow the deployment, retrieval, and a long life in the undersea environment. Note that even repeaterless cables contain a copper wire used to carry a small AC current employed by divers for locating the cable typically buried at its shore ends. In the case of a cable cut, this electrical conductor is also used to measure lumped capacitance and / or resistance which is directly proportional to cable length to the fault.

Cable designs intended for high-reliability applications are typically subjected to rigorous testing to ensure that they meet all design goals. Qualification is achieved by a combination of sea-trials and accelerated laboratory tests that can subject the cable to conditions far beyond that achievable in a sea-trial. The qualification of the cable is only valid for the specific fibres included in the testing program.

The protection of the undersea cable comes in many different varieties and eight types of protection have been identified and used. Note that a higher level of protection can be substituted for a lower level of protection, so a supplier does not need to offer all eight varieties. It is, however, standard practice to make use of many types of cable protection within one cable system. Also, note that with increased protection comes increased cost. For example, heavily armoured cable can cost more than five times the cost of unarmoured cable. Figure 32 shows the five most common varieties of submarine cable with various levels of protection, starting with Light Weight (LW) cable illustrated on the left and ending with the Double Armoured (DA) cable illustrated on the right. The intermediate cable types are Light Weight Protected (LWP), Single Armoured Light (SAL) and Single Armoured (SA).

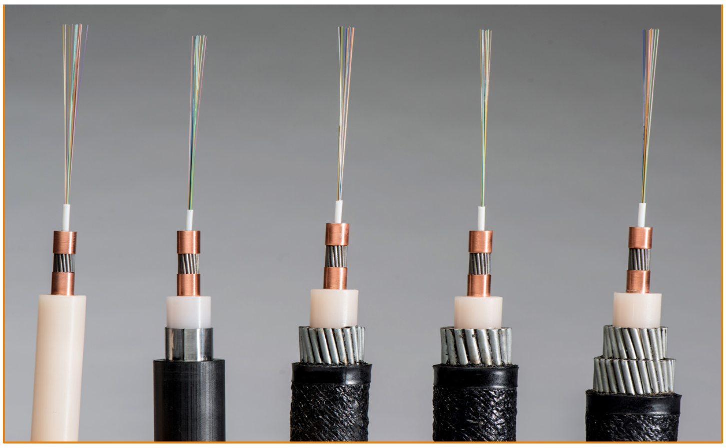


Figure 32: Five varieties of submarine cable with various levels of protection

Source: SubCom

A basic cable structure for deep water application contains all the minimum elements to support deployment, recovery, transfer electrical energy and to hold the optical fibres, but with no armour and it is the least expensive. Since this structure is the lightest and the least expensive, it is used for the cable system as much as possible. This cable type is usually called deep-water or light weight cable and the cable diameter ranges from 12 to 21 mm depending on the manufacturer and its requirements, with 17 mm being a common value.

Around this basic structure, the suppliers offer various levels of armour to protect against abrasion. The armour may be nothing more than extra polyethylene and / or a thin steel tape inside the cable. These cables are called lightweight protected, fish-bite protected, special-purpose application or light weight screened, depending on the manufacturer's marketing and design.

In shallow water, where the risk of abrasion and ship damage is the greatest, steel armouring wires are added to the basic structure in either one layer (single armoured) or two layers (double armoured with a diameter of about 38 mm – see Figure 33 below). Often this armouring comes in lightweight or heavyweight options with heavy armouring using thicker and stronger armouring wires.

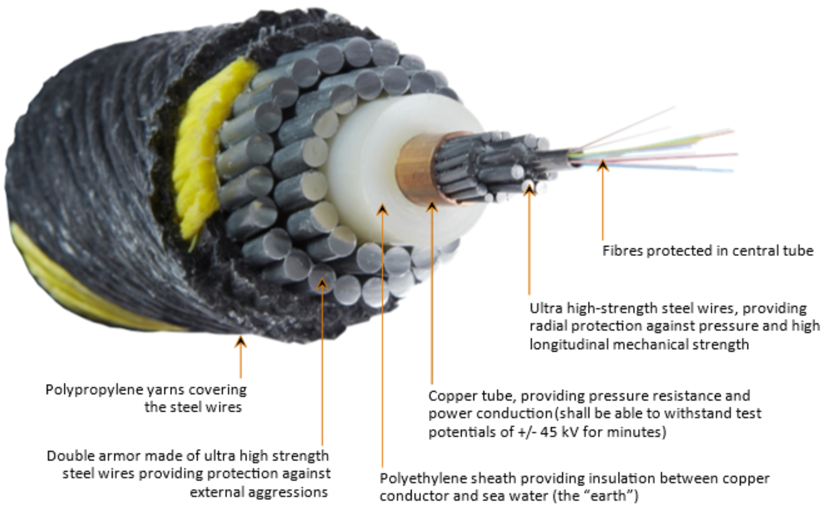


Figure 33: Example of double-armoured cable

Source: Pioneer Consulting / Nexans

The hydrostatic pressure at the ocean bottom can be significant, and the cable design must support this pressure without collapsing. Cables in the Atlantic and Pacific oceans are regularly called upon to rest in water depths as much as 6,000metres where the pressure is approximately 600 atmospheres. The water temperatures of the ocean's bottoms range from -5°C in deep salty regions of the ocean to a maximum of about +35°C in shallow equatorial waters. The temperature requirements for storage and transportation are likely much wider; usually -20°C to +50°C.

The heavy weight of these armoured cables (about 4 kg per meter for double armoured cable) limits their use to within shallow waters where they are mostly needed as the weight of long lengths of armoured cable suspended in deep water will exceed the tensile strength of the cable itself.

Submarine cables are subject to their most extreme stress when they are being deployed and recovered, with the recovery repair being the most challenging of the two operations. The cable needs be strong-enough to support its own weight and the weight of any repeaters or branching units in the line. Often there is more than 5 km of cable hanging off the back of the cable ship which also adds to the weight. In addition, the cable may also be subject to further force required to free it from the seabed due to intentional burial of the cable or self-burial which may occur over time in areas of soft seabed.

4.5.2. Constraints on Existing Landing Stations

As previously mentioned, there are often practical, technical, and commercial synergies that can be gained if the opportunity for collocating with existing submarine cables can be leveraged.

The existing cable landing stations identified as key to this report were Shefa-2, Tampnet, NO-UK and Havhingston. However there are limited opportunities for collaboration owing to a variety of reasons as explained in Section 3.6. The one exception is Tampnet, who have an unused, 2km long, 12 fibre-pair Pre-Laid Shore-End (PLSE) which would provide an excellent opportunity for reduction of cost installation time and permitting, should an arrangement with Tampnet be possible. It is important to note that while this does seem like a good prospect, the existing 12 fibre-pairs would severely limit the fibre-count from Tampnet heading south. Additionally, the status of this cable is unknown, as is the fibre type. These factors combined may make this PLSE unfavourable, however the case for a terrestrial route to Cruden Bay and subsequent marine route south is still valid, as is potentially collocating in Tampnet's landing station.

4.6. Summary of Route Development Options

Spatial analysis using GIS was carried out using a large evidence base of the physical and environmental limitations in order to develop the requested routes (Figure 2). The result was alternative proposed routes, as shown in Figure 34.

Recommendations on factors affecting route options mostly refer to early engagement with affected stakeholders. A list of potential stakeholders is provided in Appendix 4.

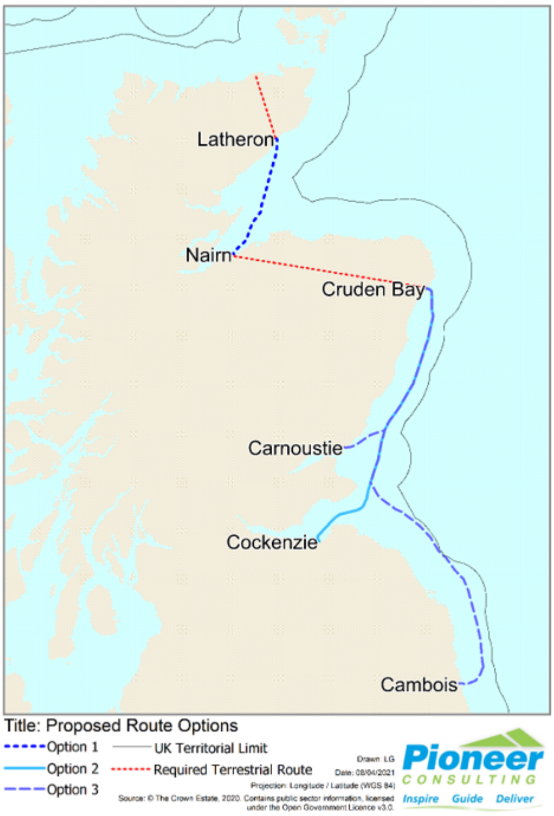


Figure 34: Proposed route options

The requested route Option #1, going south from Thurso / Dunnet Bay, was considered unfeasible given the physical factors: strong currents making installation very complex, and rock seabed creating the need for a surface lay making pinning of the cable to rock necessary which adds to time and cost. The alternative proposed landing at Latheron is the current landing location of the Beatrice Offshore Windfarm export cables. Despite the rock seabed at Latheron, the fact there is another cable here indicates a clear approach, which is ideal for landing another cable. Separation distances will need to be coordinated between the cable owners.

Nairn was selected as a landing point for Moray given the complexity of the approach at Inverness: a complex coastline resulting in the addition of alternating courses which can lead to an increase in faults, and sandbanks which can increase the complexity of installation. Even though sandbanks are present off Nairn, careful planning through survey can mitigate any risk of not achieving target burial depths.

Going from Caithness offshore to Aberdeenshire, the requested Route Option #2, is highly complex and extremely unadvisable given the number of cables and pipelines off Nigg, north of Cruden Bay. By going across land from Nairn to Cruden Bay, these cables and pipelines are avoided, and the requirement for a landing at MacDuff (one requested branch) is removed.

Landing at Dundee was requested given the presence of data centre infrastructure. Onshore fibre assets mean landing at Carnoustie is favourable and landing north and in parallel with the export cables for the Seagreen Offshore Windfarm is advisable in order to avoid crossing these cables twice and avoiding the rock seabed to the north.

Cockenzie was a requested landing given its proximity to onshore fibre assets. The proposed landing follows north of the approach of the export cables to Inch Cape Offshore Windfarm.

Cambois is the current landing position for the NSN HVDC cable, and the approach goes through, and maintains a 1 km clearance on either side of the Blyth Offshore Windfarm Demo site. Nevertheless, landing at Cambois is still preferable to landing at Whitley Bay (Havhingston cable landing) or Seaton Sluice (NO-UK cable), given the presence of the windfarm seabed lease potential off Whitley Bay and Seaton Sluice.

The overall cable distances of what was initially requested and what is proposed are provided in Table 4. The proposed subsea cable distances are almost half the requested cable distance.

Option	Requested Route	Distance (km)	Proposed Route	Distance (km)
Option #1	Dunnet ➔ Inverness	214	Latheron ➔ Nairn	80
Option #2	Dunnet ➔ Cockenzie	397	Latheron ➔ Cockenzie (via Nairn)	268
Option #3a	Dunnet ➔ Cockenzie (6 landings)	638	Latheron ➔ Cockenzie (5 landings)	296
Option #3b	Dunnet ➔ Cockenzie (5 landings)	482	Latheron ➔ Cockenzie (5 landings)	296
Option #3c	Dunnet ➔ Whitley Bay (7 landings)	676	Latheron ➔ Cambois (6 landings)	425
		2,407		1,365

Table 4: Cable distance comparison of requested and proposed routes.

In summary, the hybrid mixture of marine and terrestrial routes would appear at a high-level to provide the optimal solution to address the connectivity needs from Cruden Bay to Edinburgh. While some new build terrestrial will likely be required (red dashed lines Figure 34), the design has endeavoured to keep this to a minimum and hopefully allow for existing routes to be leveraged or augmented. Similarly, utilising a terrestrial solution between Nairn and Cruden Bay and bypassing the multitude of Oil & Gas pipelines emanating from Nigg, provides a potential solution to remove what would be an extremely difficult marine route.

4.7. Optical Design Constraints

4.7.1. Trade-offs Between Repeatered and Unrepeatered

When reach and capacity requirements allow an unrepeatered design, this approach is likely to be preferred for cable lengths up to 350-400 km due to the cost savings on repeaters, repeatered cable and PFE, higher link reliability with the absence of repeaters and PFE, room saving in landing sites in term of equipment dimensions, and higher operational security following the absence of high-voltage devices in cable landing stations. For infrastructure owners not familiar with the operation of repeatered cable systems, PFE can represent a significant change in their operational procedures and a security challenge.

Even if unrepeatered cable system designs have been demonstrated in lab environment with reach exceeding 600 km (corresponding to 500 to 550 km in practical design with operation margins), cable system operators' favour repeatered design as soon as the cable length is longer than 400 km. Over such distances, a repeatered design offers higher per fibre capacity that leads to higher cable capacity although the fibre count is smaller than in unrepeatered design: the highest fibre pair count in repeatered cable systems is 16 today and is planned to reach 24 in 2024. In addition, the cost benefit from the unrepeatered approach may disappear when the number of kilometres increases beyond 350 km because ultra-long unrepeatered reach requires numerous high-end, expensive, ultra-low-loss fibres, while a 500 km repeatered cable system can be designed with very cost-effective fibres (and with only 4 repeaters).

4.7.2. Submarine Cable System Lifetime

Submarine cable systems are often designed with a reliability specification which is typically no more than one cable ship repair in 25 years following RFS date because of failure of the submerged equipment. This excludes other causes of system failure like natural failures from abrasion, earthquakes, and mud slides or human failures such as anchoring and fishing. In practice, the economic life of repeatered cable systems which is defined by the period where annual unit cost of operations and maintenance is lower than the annual unit price of capacity on newer cable systems on the same routes, is about 20 years. In comparison, some unrepeatered cable systems are still in commercial service after 25 years. Longer operational lifetime is made possible by the absence of submerged repeaters, which increases the reliability performance of the entire submarine link. As an example, Table 5 lists the domestic unrepeatered cable systems in UK with more than 20 years of operation.

Cable System	Owner	Length (km)	Landing Points	RFS Date	Years in Operation
Scotland-Northern Ireland 2	BT	82	Carrickfergus (UK) Saltcoats (UK)	1999	22

Cable System	Owner	Length (km)	Landing Points	RFS Date	Years in Operation
UK-Channel Islands-7	Sure, BT	124	Dartmouth (UK) L'Ancresse Bay (Guernsey, UK)	1994	27
Lanis-1	Vodafone	113	Blackpool (UK) Port Grenaugh (Isle of Man, UK)	1992	29
Lanis-2	Vodafone	67	Ballywater (UK) Peel (Isle of Man, UK)	1992	29
Lanis-3	Vodafone	122	Troon (UK) Whitehead (UK)	1992	29
Scotland-Northern Ireland 1	BT	35	Donaghadee (UK) Portpatrick (UK)	1989	32

Table 5: List of domestic unrepeatered cable systems in UK with more than 20 years of operation

Five unrepeatered cable systems in the UK exceed 25 years of operation, with the Scotland-Northern Ireland 1 cable system still in commercial operation 32 years after its commissioning.

Table 6 provides 24 selected examples of unrepeatered cable systems across Europe with more than 24 years of operation.

Cable System	Owner	Length (km)	Landing Points	RFS Date	Years in Operation
Baltica	Telia Carrier, Orange Polska, TDC Group, Telenor, Slovak Telekom, Ukrtelecom	437	Gedser (Denmark) Kolobrzeg (Poland) Pedersker (Denmark) Ystad (Sweden)	1997	24
BCS East-West Interlink	Telia Carrier	218	Katthammarsvik (Sweden) Sventoji (Lithuania)	1997	24
Italy-Albania	Telecom Italia Sparkle, Albania Telecom	240	Bari (Italy) Durres (Albania)	1997	24
KAFOS	Turk Telekom	538 (3 legs)	Igneada (Turkey) Istanbul (Turkey)	1997	24

Cable System	Owner	Length (km)	Landing Points	RFS Date	Years in Operation
			Mangalia (Romania) Varna (Bulgaria)		
Ulysses 2	Verizon	210	Ijmuiden (Netherlands) Lowestoft (UK)	1997	24
Adrai-1	T-Hrvatski Telekom, Albania Telecom	440 (2 legs)	Corfu (Greece) Dubrovnik (Croatia) Durres (Albania)	1996	25
Sweden-Estonia (EE-S 1)	Telia Carrier, Telia Eesti, GN Great Nordic	240	Kärdla (Estonia) Stavsnas (Sweden) Tallinn (Estonia)	1995	26
BCS East	Telia Carrier	98	Liepaja (Latvia) Sventoji (Lithuania)	1995	26
UGARIT	Many	239	Pentaskhinos (Cyprus) Tartous (Syria)	1995	26
CADMOS	Many	230	Beirut (Lebanon) Pentaskhinos (Cyprus)	1995	26
Italy-Monaco	Telecom Italia Sparkle, Monaco Telecom	162	Monte Carlo (Monaco) Savona (Italy)	1995	26
Latvia-Sweden 1 (LV-SE 1)	Telia Carrier, Tele2, Tet, Telecom Italia Sparkle	304	Nynashamn (Sweden) Ventspils (Latvia)	1994	27
Botnia	Telia Carrier	93	Umeå (Sweden) Vaasa (Finland)	1994	27
Sweden-Finland Link (SFL)	Telia Carrier, Elisa Corporation	142	Mariehamn (Finland) Väddö (Sweden)	1994	27
PENBAL-5	Telefonica	309	Gavá (Spain) Ses Covetes (Spain)	1994	27
IP-Only Denmark-Sweden	IP-Only	20	Brondby (Denmark) Klagshamn (Sweden)	1994	27
Finland-Estonia 3 (EESF-3)	Telia Carrier, Telia Eesti	104	Helsinki (Finland) Meremöisa (Estonia)	1994	27

Cable System	Owner	Length (km)	Landing Points	RFS Date	Years in Operation
Sweden-Finland 4 (SFS-4)	Telia Carrier, Elisa Corporation	254	Norrtalge (Sweden) Turku (Finland)	1993	28
Finland-Estonia 2 (EESF-2)	Telia Carrier, Telia Eesti	98	Helsinki (Finland) Tallinn (Estonia)	1992	29
Corse-Continent 4 (CC4)	Orange	190	Cannes (France) L'Île-Rousse (France)	1992	29
Rønne-Rødvig	TDC Group	153	Rødvig (Denmark) Rønne (Denmark)	1992	29
Denmark-Sweden 16	TDC Group	15	Mosede (Denmark) Velling (Sweden)	1991	30
Denmark-Poland 2	TDC Group, Telia Carrier, Telenor	110	Gedebak Odde (Denmark) Mielno (Poland)	1991	30
Farland North	BT	150	Aldeburgh (UK) Domburg (Netherlands)	1989	32

Table 6: List of unrepeatered cable systems in Europe with more than 24 years of operation

Similar examples of unrepeatered cable system with operational life exceeding 25 years can be found in other parts of the world, and in particular in south east Asia where the geography and the presence of multiple islands are conducive to this kind of submarine cable systems.

Due to their simple technical design, unrepeatered cable systems can offer a long operational lifetime provided the marine routes are carefully selected, designed, and engineered.

4.7.3. Bandwidth Granularity and Fibre Count

With the recent introduction of Spatial Division Multiplexing (SDM) approach for repeatered cable systems, the number of fibre pairs has increased from 8 to 16 today and is expected to reach 24 in 2024, and possibly 32 in 2026. This increase in fibre pair count has a multi-fold impact on how repeatered cable systems can be monetized and amortised:

- Increase in total cable capacity through more efficient use of the electrical power used to power the cable system from its ends;
- Lower cost per 100G capacity unit due to higher cable capacity and per fibre pair due to higher fibre count;
- Lower cost of entry for fibre pair ownership;
- Facilitating the sales of dark fibre pairs to new customer types which could include large enterprises in the midterm.

As the number of fibre pairs is limited to 24 today (assuming the cable system is designed today and ready for service in 2024-2025 timeframe), the total cost of the submarine cable infrastructure will be shared by a relatively modest number of fibre pairs, making the fibre pair ownership relatively expensive. Small capacity users will have to purchase lit bandwidth services (like 100 Gbps circuits); which will force the submarine cable infrastructure owner to deploy and operate transmission equipment connected to each extremity of the submarine cables.

Unrepeatered cable systems can typically offer 96 fibre pairs as in the CrossChannel Fibre cable system to be deployed across the English Channel. Such a large number of fibre pairs make fibre pair ownership more affordable and proportionally reduces the annual operation and maintenance fees attached to fibre pair ownership.

4.8. Suggested High Level Optical Designs

Based on the design of the proposed routes and the associated submarine cable lengths, an unrepeatered cable system design is seen as the most suitable approach. This is due to:

- High Capacity per Fibre Pair Achievable - The maximal submarine cable length is between Cruden Bay and Cambois landing sites (299 km). Considering the 20 km terrestrial extension to extend the submarine cable length to Stellium data centre in Wallsend, the transmission distance between Cruden Bay landing site and Stellium data centre in Wallsend is 319 km. This distance can be spanned using an unrepeatered cable system with a capacity exceeding 10 Tbps per fibre pair using current transmission equipment technology.
- Simple Operation - An unrepeatered cable system design does not require high-voltage power feed equipment to remotely power submerged active repeaters. This will greatly facilitate the operation of the submarine cable infrastructure by its owner/operator.
- Long Operational Lifetime - As discussed in Section 4.7.2, unrepeatered cable systems can be operated over a longer period than repeatered cable systems.
- High Fibre Pair Count - An unrepeatered cable system design will allow a high fibre pair count, with 96 fibre pairs being a common figure today. Such a fibre pair count can minimize the cost of fibre pair ownership and allows bandwidth to be sold at the fibre pair granularity. This avoids the submarine cable infrastructure owner/operator having to sell lit bandwidth services and install and operate transmission equipment. Customers of dark fibre pairs will deploy and operate their own transmission equipment over the submarine cable infrastructure shared by the multiple fibre pair owners.

4.8.1. Option 1

Figure 35 depicts the high-level optical design for Option 1. The distance between the Latheron and Nairn landing sites is approximately 80 km and can be easily spanned with no subsea repeater using conventional transmission equipment designed for terrestrial networks at each extremity.

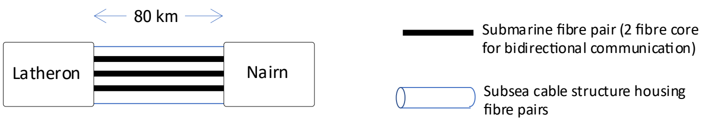


Figure 35: Option 1 high-level optical design

Source: Pioneer Consulting

4.8.2. Option 2

Figure 36 represents the high-level optical design for Option 2. In this option, due to marine constraints off the Scottish coasts, the design recommends including a land-based segment between Nairn and Cruden Bay.

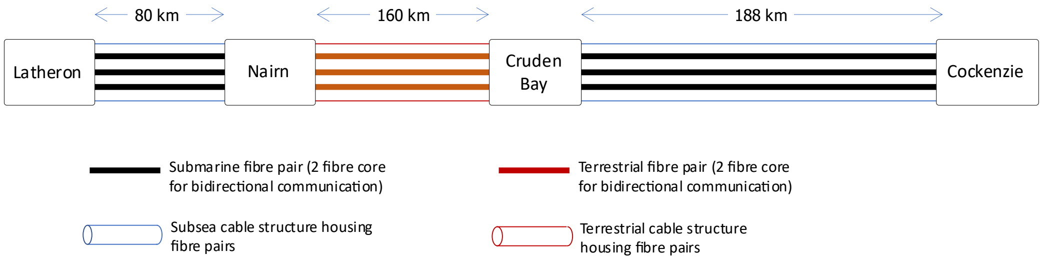


Figure 36: Option 2 high-level optical design

Source: Pioneer Consulting

The distance between the Cruden Bay and Cockenzie landing sites is approximately 188 km and can be easily spanned with no subsea repeater using transmission equipment designed for long-haul terrestrial networks at each end.

Assuming the quality of the terrestrial fibres between Nairn and Cruden Bay is sufficient, data can be transported between Latheron and Cruden Bay with no intermediate equipment in Nairn. Such an arrangement will lower the cost per unit of capacity for users requiring connectivity between Latheron and Cruden Bay.

4.8.3. Options 3a/3b

Figure 37 provides the high-level optical design for Options 3a/3b. Compared to Option 2, this option adds an intermediate landing in Carnoustie between Cruden Bay and Cockenzie. The intermediate landing is achieved using a branching unit that routes a given number of fibre pairs from the Cruden Bay - Cockenzie trunk to the branch landing in Carnoustie.

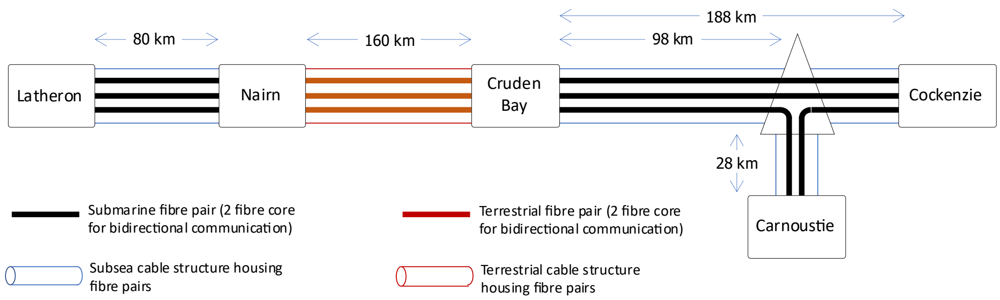


Figure 37: Option 3a/3b high-level optical design

Source: Pioneer Consulting

Options 3a/3b do not add any new constraints as far as optical design is concerned. At each extremity (Cruden Bay, Cockenzie trunk and Carnoustie), installation of transmission equipment designed for long-haul terrestrial networks will allow high-capacity transmission between the landing sites (at a capacity exceeding 10 Tbps per fibre pair).

4.8.4. Option 3c

Figure 38 provides the high-level optical design for Option 3c. Compared to Options 3a/3b, this option extends the cable trunk further south to Cambois. Cockenzie is now connected to the trunk via a branching unit. The trunk can be extended from Cambois landing site to the Stellium data centre located in Wallsend using terrestrial fibre extension, with no intermediate transmission equipment in Cambois for express fibre pairs to be terminated in Stellium data centre.

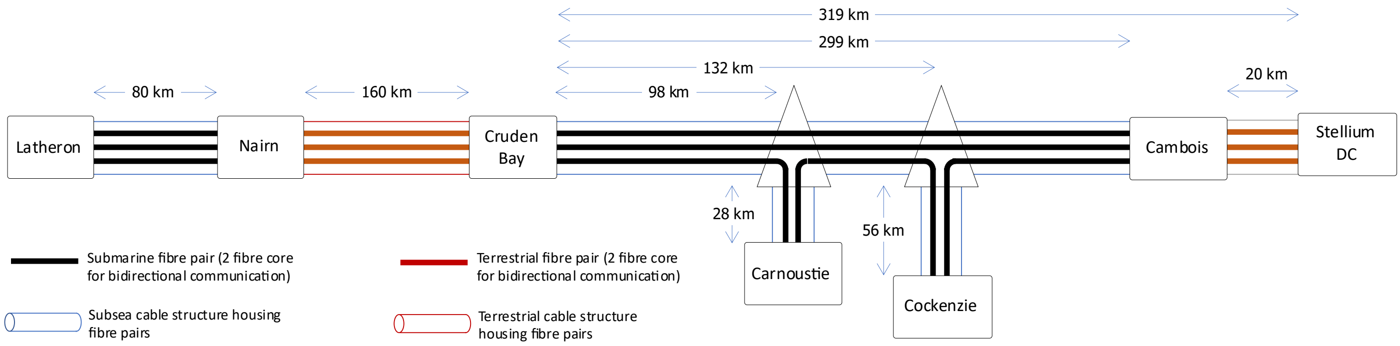


Figure 38: Option 3c high-level optical design

Source: Pioneer Consulting

The transmission distance between the Cruden Bay landing site and Stellium data centre in Wallsend is 319 km and can be spanned using high-end transmission equipment designed for long transmission distance over a single span. There is no need to introduce submerged active repeaters or passive Remote Optically Pumped Amplifiers (ROPAs) in the submarine cable. Current transmission equipment technology offers a capacity exceeding 10 Tbps per fibre pair over 320 km distance assuming low-loss optical fibres.

5. Stage 3: Engineering & Costing

5.1. Introduction

This stage assesses the engineering and costing for each of the three options pre-defined at the time of the proposal, plus sub-options, and re-designed through this work. This includes:

- Review of the suitable technologies;
- Feedback from selected key suppliers to confirm the contemplated optical system design is practically achievable with currently available technologies;
- Collection of price information to fuel the costing stage;
- High-level cost structure for the various proposed options.

5.2. Suitable Technologies

As discussed in Section 4.8, the design is for an unrepeatered system for all the proposed options. This unrepeatered system design offers operational simplicity, large fibre pair count, and attractive price point as there is no need for PFE equipment and submerged active repeaters. In short, the proposed unrepeatered system design offers a totally transparent optical path between the landing sites, which is limited only by the submarine link attenuation.

The enabling technologies include:

- Unrepeatered cable structure with a sufficient level of protection to guarantee the integrity of the optical fibre cores against mechanical aggressions given the low water depths. A double armoured cable structure is proposed;
- Optical fibre exhibiting a linear attenuation (expressed in dB/km) low enough to allow unrepeatered transmission with no need for submerged Remote Optically Pumped Amplifiers (ROPAs) over 320 km distance. The use of low-loss fibre with an attenuation no greater than 0.17 dB/km is recommended;
- Standard and customarily used marine operation and installation technologies for both cable route survey and cable installation.

5.3. Supplier Feedback

Two large suppliers of transmission equipment for unrepeatered cable systems have been approached as part of this study. Both suppliers confirm the capability of their current product offering to offer more than 10 Tbps of capacity per fibre pair on unrepeatered distance up to 320 km with no Remote Optically Pumped Amplifiers (ROPAs) inserted in the submarine cable system, assuming low-loss optical fibre with attenuation no greater than 0.17 dB/km. This feedback confirmed the view that an unrepeatered optical system design is the appropriate choice for the proposed routes.

The study has also confirmed the availability of 192 fibre core unrepeatered cable from at least one well-established submarine cable supplier based in Europe. A 192 fibre cable is currently the recommended pragmatic upper-limit for an unrepeated marine cable, due to practical repair considerations.

The marine operation/installation suppliers to be involved in this infrastructure project will not require any specific tools, vessels, or technologies. Standard equipment, processes, and procedures will used by the supplier(s) to survey the cable route and install the cable on the seabed.

5.4. High-Level Cost Models

Using up-to-date cost data, this section provides a high-level cost structure for the various proposed routes. The basic assumptions include:

- Detailed survey of each cable route will be required to engineer and finalise the submarine cable route;
- Double armoured cable equipped with 192 fibre cores (offering 96 fibre pairs);
- 100% burial all along the cable route to protect the cable against external aggression (e.g., from anchoring or fishing activities);
- Requirement to build a beach manhole at all landing sites;
- Insertion of passive branching unit in Option 3a/3b and Option 3c (with neither optical nor electrical switching capabilities).

The high-level costing provided in Table 7 to Table 10 includes marine route survey and engineering, submarine cable supply and installation, shore end work to land the submarine cable, beach manholes to mechanically anchor the submarine cable to the shore and submerged branching unit when required.

For clarity, the following items have not been considered in the high-level costings:

- Any terrestrial requirements, specifically the Dunnet Bay to Latheron and Nairn to Cruden Bay sections.
- Fronthaul requirements i.e. from the BMHs back to the desired termination points (although these distances have been considered in section 4.8, High Level Optical Design).
- License or permitting fees, environmental studies and supporting documents or application costs.
- All legal agreements, Fisheries Liaison Officer requirements and compensation negotiations.

The high-level costings correspond with the requested RFQ Options and alternate proposed routes shown in Table 7.

Option 1 (Latheron - Nairn)			
Subsea Length (km)	80		
Survey		£	1,100,000
Cable Supply		£	1,500,000
Cable Installation		£	2,500,000
Landings	2	£	100,000
Beach Manhole (BMH)	2	£	120,000
Branching Unit	0	£	-
		£	**5,320,000**

Table 7: High-level costing for Option 1

Option 2 (Latheron - Cockenzie, via Nairn)

Subsea length (km)	268		
Survey		£	3,600,000
Cable Supply		£	4,900,000
Cable Installation		£	8,500,000
Landings	4	£	200,000
Beach Manhole (BMH)	4	£	240,000
Branching unit	0	£	-
		£	**17,440,000**

Table 8: High-level costing for Option 2

Option 3a/3b (Latheron - Cockenzie, 5 landings)

Subsea length (km)	296		
Survey		£	3,900,000
Cable Supply		£	5,400,000
Cable Installation		£	9,300,000
Landings	5	£	250,000
Beach Manhole (BMH)	5	£	300,000
Branching unit	1	£	400,000
		£	**19,550,000**

Table 9: High-level costing for Option 3a/3b

Option 3c (Latheron - Cambois, 6 landings)

Subsea length (km)	463		
Survey		£	6,100,000
Cable Supply		£	8,500,000
Cable Installation		£	14,600,000
Landings	6	£	300,000
Beach Manhole (BMH)	6	£	360,000
Branching unit	2	£	800,000
		£	**30,660,000**

Table 10: High-level costing for Option 3c

5.4.1. Summary

For clarity we have labelled the individual sections of the proposed hybrid solution described in Section 4.6 and in Figure 39 below, as "*segments*" so as not to be confused with the Options listed in the RFQ.

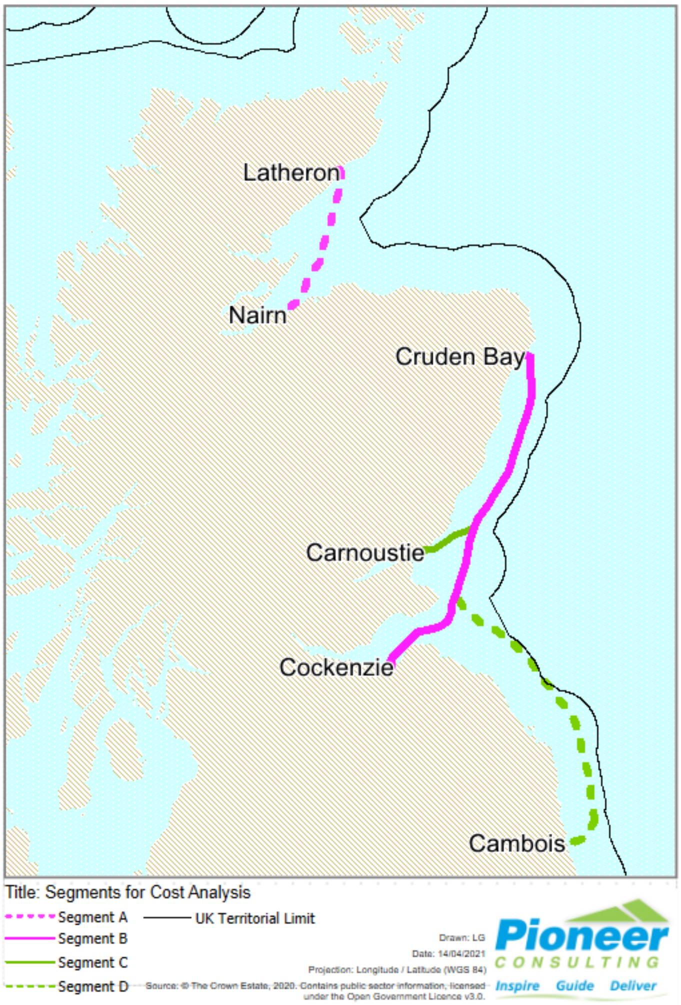


Figure 39: Proposed hybrid solution

Therefore, in summary, the incremental costs for each segment are as follows in Table 11.

Segment	Segment Description	Costing
Segment A	Latheron ➔ Nairn (pink dashed)	£5,320,000
Segment B	Cruden Bay ➔ Cockenzie (pink solid)	£12,120,000
Segment B & C	Cruden Bay ➔ Cockenzie, branch to Carnoustie (pink solid & green solid)	£14,230,000
Segment B, C & D	Cruden Bay ➔ Cambois, branches to Carnoustie & Cockenzie (pink solid, green solid & green dashed))	£25,340,000

Table 11: Incremental costs of proposed segments

6. Program Management

6.1. Approach

In terms of complexity, any submarine build envisioned within this report would not be considered overly complicated. In fact, the proposed solution (a hybrid mix of terrestrial and marine) lends itself well to being broken into smaller pieces, which in-turn enables any such project to be built in distinct, independent stages, suggesting suitability for a disaggregated program management approach.

6.2. Build Options (Turn-key vs Disaggregated)

Disaggregation essentially means to break into smaller, constituent parts. In the case of a submarine cable system, these smaller parts mean the fundamental elements required to build the system i.e. the marine plant procurement, the marine survey, permit acquisition, beach manhole construction, marine installation, and any other parts required, can all be carried out in phases over a period of time. A system integrator function is required to define the scope of each constituent part and ensure there are no scope gaps, and to integrate the component parts to form a seamless system.

The alternate to a disaggregated project is a turn-key project, where the entire subsea system is purchased from, and provided by, a single vendor. The main advantage is that is provides a high level of confidence of a fully working, integrated system and importantly a single point of accountability end-to-end, with clear lines of demarcation.

While from the outside it may seem seamless, the turn-key provider is essentially performing the role of the disaggregated system integrator, whilst also taking on the commercial risk and overall responsibility.

A primary driver in the decision for disaggregation vs turn-key provision is the approach of the end client to risk and the level of risk an owner is prepared to accept. Historically, smaller, specifically unpowered systems have been installed using a disaggregated approach. Given the nature of the proposed solutions presented in this report, a level of disaggregation would seem to be a good fit with the aim of SFT.

6.3. Project Plan of Works

The length and sequence of any submarine build will have many input factors, both project specific and external i.e. permitting durations or vessel availability. The high-level Plan of Work in Table 12 can be considered as typical for this size and complexity of project, with a range of 20 to 24 months being a realistic timeframe.

<------------------------------- Estimated 20 - 24 month program ------------------------------- >

Activity Description		Months																						
Preparatory Actions																								
	Desk Top Study	2	■	■																				
	Permit Feasibility Study	1			■																			
	Cable Route Study	1			■																			
Permitting & Regulatory																								
	Marine Licence Application - Scoping	4					■	■	■	■	■													
	Seabed Survey Licence and Exemptions						■	■	■															
	Marine Licence Application - Installation	6														■	■	■	■	■	■			
	Seabed Lease	6														■	■	■	■	■	■			
Procurement																								
	Marine Survey	2						■	■															
	Marine Cable	2									■	■	■											
	Marine Installation	3										■	■	■	■									
Marine Route Survey																								
	Geotechnical survey	1										■												
	Geophysical survey	2											■	■										
	pUXO survey	1													■									
Cable Manufacture		6													■	■	■	■	■	■				
Marine Installation		2																					■	■

Table 12: High-level plan of work

The critical path for a submarine cable build is usually specific to each project, but the more common driving factors are permit acquisition, vessel availability for both route survey and installation, availability of cable manufacturing capacity, and ability of the project sponsor to commit appropriate funds.

Appendices

Appendix 1 - References

1. European Commission. 2012. Guidance on Aquaculture and Natura 2000 Sustainable aquaculture activities in the context of the Natura 2000 Network. Available online [http://ec.europa.eu/environment/nature/natura2000/management/guidance_en.htm].

2. IEEM. (2010). Guidelines for ecological impact assessment in Britain and Ireland: Marine and Coastal. Available online at [http://www.cieem.net/ecia-guidelines-marine-].

3. I.A. Malcolm, J. Godfrey and A.F. Youngson. (2010). Review of migratory routes and behaviour of Atlantic salmon, sea trout and European eel in Scotland's coastal environment: implications for the development of marine renewables. Available online [https://data.marine.gov.scot/sites/default/files/SMFS%20vol%201%20No%2014.pdf].

4. Scottish Tourism Alliance. (2020). Giant Strides 2020-2025. Available online at [https://scottishtourismalliance.co.uk/marine-tourism/].

Appendix 2 - Glossary

Bandwidth	In the context of telecommunications, bandwidth refers to the maximum data transfer rate of a network or internet connection. It measures how much data can be transferred over a particular connection in a given time. It is often measured in terms of megabits per second (Mbit/s) for residential access to internet, gigabits per second (Gbit/s) or terabits per second (Tbit/s) for submarine cable systems.
Broadband	A high-capacity transmission technique using a wide range of frequencies, which enables a large number of messages to be communicated simultaneously. This term is often used to describe high-bandwidth services or infrastructure from the users' perspective.
Cable Landing Station (CLS)	A Cable Landing Station (CLS) is the building at which the submarine cable connects into the land-based infrastructure or network.
Cloud-based service	A cloud-based service is any service made available to users on demand via the Internet from a cloud computing provider's server as opposed to being provided from a company's own on-premises servers. Cloud services are designed to provide easy, scalable access to applications, resources, and services, and are fully managed by a cloud services provider.
Cloud computing	The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.
Data centre	Buildings or part of buildings that house the servers that store, manage and disseminate data and information systems. The basic business of data centre operators is to provide space, power, and security services.
Edge data centre	Smaller data centre facilities located close to the populations they serve that deliver cloud computing resources and cached content to end users. They typically connect to a larger central data centre or multiple data centres. By processing data and services as close to the end user as possible, edge computing allows organizations to reduce latency and improve the customer experience.

Fibre optic links	High-speed data transmission medium made of tiny glass filaments that carry light beams. Digital data is transmitted through the cable via rapid pulses of light emitted by high-frequency specialized transmission equipment.
Hyper-scale data centre	A scalable data centre that can expand on the needs of the business.
Internet Exchange Point (IXP)	An Internet Exchange Point or IXP is the infrastructure that allows internet and content providers to interconnect with each other directly and without recourse to third party carriers (to achieve interconnection in remote locations, e.g. Singapore). This has many advantages, but primarily it reduces the need to interconnect to the global network for local traffic, thus reducing costs and improving the quality of data and content exchange.
Internet of Things (IoT)	The network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these things to connect and exchange data, creating opportunities for more direct integration of the physical world into computer-based systems, resulting in efficiency improvements, economic benefits, and reduced human exertions
Internet Service Provider (ISP)	An Internet service provider (ISP) is an organization that provides services for accessing, using, or participating in the Internet. Internet service providers can be organized in various forms, such as commercial, community-owned, non-profit, or otherwise privately owned. Internet services typically provided by ISPs include Internet access, Internet transit, domain name registration, web hosting, Usenet service, and colocation.
IP transit	IP Transit is a service where an Internet Service Provider (ISP) allows traffic to travel through their network to its final destination.
Latency	Network latency is measured as either one-way (the time from the source sending data to the destination receiving it), or round-trip delay time (the one-way latency from source to destination plus the one-way latency from the destination back to the source). Round-trip latency is more often quoted because it can be measured from a single point. Round-trip latency can be named Round-Trip Delay time (RTD) or Round-Trip Time (RTT). By way of reference, the nominal delay in one kilometre of fibre is 5 microseconds (5 □s).

Over-the-Top providers (OTTs)	A term used to refer to content and other service providers that distribute streaming media as a standalone product directly to consumers over the Internet, bypassing telecommunications, multichannel television, and broadcast television platforms that traditionally act as a controller or distributor of such content.
Point of Presence (PoP)	A Point of Presence (PoP) is where two or more networks or communication devices share a connection. POP primarily alludes to the demarcation point, access point or location that connects these networks or devices. It is also the foundation that allows distant people to connect to the Internet.
Resilience	In telecommunication networking, resilience is the ability to provide and maintain a similar or acceptable level of service in the face of faults and challenges to normal operation (like cable cuts in one of the submarine cable systems connecting one country to the rest of the world).
Server	In computing, a server is a device that provides functionality for other devices or programs, called "clients". Servers can provide various functionalities, often called "services", such as sharing data or resources among multiple clients, or performing computation for a client. A single server can serve multiple clients, and a single client can use multiple servers. A client process may run on the same device or may connect over a network to a server on a different device.
Submarine cables	Any kind of cable that is laid on the seabed, down to 8,000 metre water depths. In this report, submarine cables refer to fibre optic cable for telecommunication purposes. Submarine cables can be a few or multi-thousand kilometre long. Beyond 400 km, subsea cable systems include periodic submerged repeaters and are named 'repeatered cable systems'.
Virtual Reality (VR)	Virtual Reality (VR) is a simulated experience that can be similar to or completely different from the real world. Applications of virtual reality can include entertainment (i.e. video games) and educational purposes (i.e. medical or military training).

Appendix 3 - Data Stewardship and Recommendations

Data sources were interrogated through open-source platforms and obtained from the owner, as detailed In Table 11.

Marine Planning Constraints Theme	Data source	Data limitations
Environmental - rock seabed	JNCC, UKSeaMap 2010	This data is based on BGS data and has a high confidence level attributed.
Environmental - sandbanks	JNCC, UKSeaMap 2010	This data is based on BGS data and has a high confidence level attributed.
Physical - pipelines	Cables, pipelines and windfarms in Scotland included in: "Energy_Infrastructure_Agreements" and "Designated_Areas" downloaded from [https://www.crownestatescotland.com/maps-and-publications] on 03/03/2021.© Crown Estate Scotland 2021 The Crown Estate: windfarms included in: "Offshore_Wind_Site_Agreements__England_2C_Wales__26_NI__2C_The_Crown_Estate" and "Offshore_Wind_Leasing_Round_4_Characterisation_Areas_(England,_Wales_and_NI)_-_The_Crown_Estate" download from [https://opendata-thecrownestate.opendata.arcgis.com/search?groupIds=f0d0ec92da76434d9e91f2e4dcb3a99f] on 03/03/2021.© The Crown Estate, 2020.	The data used in this project is lease areas, and may over-estimate the scale of seabed usage. Early consultation with offshore operators is recommended to maximise the use of space. This data was downloaded on 03/03/2021 and more recent data may be available.
Physical - Cables		
Physical - Offshore Renewables		
Other sea users - marine traffic and maritime safety	Data procurement out-with scope.	Not applicable
Other sea users - fishing - seabed contact gear	Fishing Activity for UK Vessels 15m and over 2012 - 2017. Downloaded from [https://data.gov.uk/dataset/4bd80f1a-4ead-44c5-b3fa-975da1cb4d7d/fishing-activity-for-uk-vessels-15m-and-over-2016#licence-info] on 03/03/2021.	Fisheries statistics on landings based on the VMS are currently not available for vessels under 12 m length. This does not facilitate a site-specific assessment of effects, and given the scale of this data

Marine Planning Constraints Theme	Data source	Data limitations
	"Contains MMO information licensed under the Open Government Licence v3.0."	proportionate to a typical 'impact zone' of a cable, any fishing activity will be overestimated.
Other sea users - recreation and tourism	No data available.	Not applicable.
Legislative - shipwrecks	"Shipwrecks" and "wreck areas" was downloaded from the Admiralty Marine Data Portal [https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal] on 03/03/2021. "© UKHO copyright and database right 2021. Contains public sector information, licensed under the Open Government Licence v3.0, from UKHO".	Locations are approximate. The exact location of shipwrecks and any materials associated with them can only be determined by a fine-scale geophysical survey.
Legislative - Nature Conservation Designated Areas	NatureScot, nature conservation designated areas / Natura 2000 Network. Data downloaded from [http://gateway.snh.gov.uk/natural-spaces/index.jsp] on 03/03/2021. "Contains SNH information licensed under the Open Government Licence v3.0."	This data was downloaded on 03/03/2021 and more recent data may be available.
Nature Conservation - seabed species and habitats	NatureScot, GEMS dataset includes Appendix 1 and 2 species and habitats. Data downloaded from [http://gateway.snh.gov.uk/natural-spaces/index.jsp] on 03/03/2021. "Contains SNH information licensed under the Open Government Licence v3.0."	This data was downloaded on 03/03/2021 and more recent data may be available.
Nature Conservation - essential fish habitat	Coull, K.A., Johnstone, R., and S.I. Rogers. 1998. Fisheries Sensitivity Maps in British Waters. GIS Layers downloaded from Cefas Data Hub: [http://data.cefas.co.uk/#/View/149] on 03/03/2021.	Spawning and nursery ground data is very broadscale resulting in a low confidence in its validity.
Nature Conservation - diadromous fish	No data out with the designated areas.	Not applicable.
Nature Conservation - Cetaceans	No data out with the designated areas.	Not applicable.
Basemaps - territorial waters	Downloaded from The Crown Estate [https://opendata-thecrownestate.opendata.arcgis.com/search?groupIds=f0d0ec92da76434d9e91	No limitations.

Marine Planning Constraints Theme	Data source	Data limitations
	f2e4dcb3a99f] on 03/03/2021. © The Crown Estate, 2020. Contains public sector information, licensed under the Open Government Licence v3.0.	

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Appendix 4 - Potential Stakeholders in Marine Site Selection

Theme	Stakeholder Organisation
Archaeology / wrecks	Historic Environment Scotland and English Heritage
Offshore windfarms	Beatrice (Talisman)
Oil and gas operators	BP (Forties pipeline at Cruden)
Cable owners	Tampnet UK Ltd (at Cruden); Repsol Sinopec Resources (at Latheron)
Marine Licensing	MSLOT (Scotland); MMO (England)
Seabed Lease and Seabed Survey Licence	Crown Estate Scotland and The Crown Estate
Maritime Safety and Navigation	MCA
Fishing Associations	Scottish Fishermen’s Association; The Scottish Pelagic Fishermen’s Association Ltd (SPFA); and Scottish Creel Fishermen's Federation (SCFF).
Recreation	RYA
Nature Conservation	NatureScot and Natural England
Diadromous fish	Marine Scotland Freshwater Lab

Appendix 5 – Carbon Emission Costs

Appendix 5: 1. Executive Summary

This appendix looks at the cost of the proposed project in terms of greenhouse gas emissions (GHGe). When examined at a macro level studies have shown that the direct balance between the GHGe cost to deploy digital solutions, and the benefits they bring, favours the solution and results in savings in GHGe. However, data collection for digital solutions, whilst growing, is still lacking in some areas including around the infrastructure elements of the overall solution. Understanding the relative GHGe of the solutions under consideration is a requirement of the renewed guidance for UK Government Programmes[1].

From the detail in the report, geographic factors have determined that a hybrid land and subsea approach be adopted to bring fixed connectivity from the North East of Scotland to sites in Northern England via sites in Scotland's Central Belt.

Using a number of sources from academic papers to vendor reports, FarrPoint has concluded the following in relation to the **North-Eastern Scotland: Subsea Connectivity Feasibility Study**:

For Option 1: the route from Thurso to Cockenzie will result in **7,046** tonnes CO_2 equivalent (tCO_2) over the deployment of the infrastructure and the maintenance of subsea asset over a 25-year lifecycle. For completeness the asset will also require a further **4,526** tCO_2 for asset recovery.

Total for programme: **11,572 tCO_2**. For some context, this is the equivalent in GHGe terms of 36 transatlantic journeys for a Boeing 747.

For Option 2: the route from Thurso to Cambois, will result in **9,398** tCO_2 over the deployment of the infrastructure and the maintenance of subsea asset over a 25-year lifecycle. For completeness the asset will also require a further **6,164** tCO_2 for asset recovery.

Total for programme: **15,562 tCO_2**. Again, for some context, this is the equivalent in GHGe terms of 48 transatlantic journeys for a Boeing 747.

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[1] Green Book, Revised Guidance. Found at: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

Appendix 5: 2. Introduction

Purpose of this Appendix

This appendix adds to the work carried out in the main document by looking at the impact this proposed project will have on GHGe. GHGe are an important consideration in light of the Scottish Government's target to achieve net-zero GHGe by 2045.

Net-zero is a shorthand term that means that the GHGe entering into the atmosphere are equally balanced by those that are removed. Scotland's climate change legislation sets a target date for net-zero emissions of all GHGe by 2045 and a 75% reduction from 1990 levels by 2030. For the rest of the UK, as well as the majority of the EU, 2050 remains the net-zero target date.

Net-zero GHGe should not be confused with net-zero carbon, or net-zero CO_2. It is important to note that CO_2 is just one of many greenhouse gases (GHG) albeit the largest by volume in terms of emissions. Net-zero GHGe is more accurately described as net-negative CO_2. This distinction is an important one as the terms used in climate change discussion on the subject of net-zero often interchange GHGe and CO_2.

Structure

This appendix does not replay any of the rationale for the selection of options within the main document. It takes the options and models their approach in GHGe terms to determine the CO_2 equivalent of the deployment of subsea cable and the necessary land based (terrestrial) infrastructure.

- Section 3 sets out the role digital can play in helping society achieve net-zero and climate change goals.
- Section 4 details the methodology employed and the assumptions and limitations of the approach used in determining the GHGe of the programme.
- Section 5 uses the output of the main study to determine the values for GHGe along each section of the build. A series of tables throughout this section build up to explain GHGe values by option and method (subsea and/or terrestrial).
- Section 6 is a summary of section 5 with a comparison between the subsea approach and the alternative impact of a full terrestrial build.

Appendix 5: 3. Background

The Role of Digital

FarrPoint believe that digital connectivity, and the solutions it enables, will result in a positive benefit to the net-zero targets for local and national governments. It is possible to conclude that digital connectivity will reduce GHGe at a level beyond that which is required to build and maintain the infrastructure supporting it. There is clear evidence to support a view that for every x-tonnes of GHGe produced to create digital infrastructure, a value >x tonnes is saved through the resulting benefits of digital services. An important consideration in drawing this conclusion was an understanding of the GHGe in the deployment of digital infrastructure including mobile mast sites and civil engineering programmes to build e.g. new fibre infrastructure.

Given that 97% of global communication[2] is transported over subsea cables, understanding the GHGe impact of subsea cable systems is an important factor in developing a balance sheet approach to infrastructure rollout and all associated benefits.

[2] Found at: https://www.escaeu.org/articles/submarine-telecommunications-cables/

Appendix 5: 4. Approach

Methodology

The methodology adopted is centred on desk-based research using a combination of academic and industry sources as well as access to previous studies undertaken by FarrPoint.

Where possible the appendix refers to research based upon a full life cycle assessment of the infrastructure given that there are clearly defined stages to its deployment, use and, where appropriate, recovery. Assumptions and limitations used are detailed in further sections.

Within this appendix, GHGe is expressed in terms of GHGe per km and the research conducted by FarrPoint collates data sources in a manner that facilitates an appropriate value consistent with this emission weight by distance ratio (tCO_2/km). The aggregate values for this relationship take into account a number of activities within a subset of vehicle (ship) roles set out below:

1. Survey
2. Deployment/Installation
3. Operation and Maintenance
4. Recovery.

Within the four categories the following subsets have been assessed as they each consume fuel in a manner that needs to reflect engine load, rather than simply a value per km:

a) In port activity (auxiliary engine use)
b) At sea/infra deployment (main engine(s))
c) Manoeuvring (main engine(s))

Comparisons between the GHGe of subsea cable deployment and use are also made with an alternative approach using land-based assets, either new or existing. FarrPoint has derived these GHGe through in-house modelling.

The value for the amount of Heavy Fuel Oil (HF) consumed per km travelled has been taken from a number of sources referencing back to the tables included in the report on 'European Commission Quantification of emissions from ships associated with ship movements between ports in the European Community'[3].

Assumptions

The following assumptions have been made in this analysis:

- The usable cable asset life has been determined to be 25.

[3] Found at: https://ec.europa.eu/environment/air/pdf/chapter1_ship_emissions.pdf

- Transportation GHGe for the cable to the ship have not been included. It is assumed that the relative GHGe of transport is unlikely to have a material impact on the overall GHGe cost of the project.
- The availability of fibre where required on land has been modelled by FarrPoint and where dark fibre is available from BT, it is assumed the project can make use of it. GHGe of this capacity has been calculated as if new fibre is to be deployed in existing ducts.
- In all instances it has been assumed that the cable ship returns to a point of origin; in the case of this project the ship will return to a berth in Latheron.
- It has also been assumed that the deployment of the subsea cables occurs as a single operation rather than a number of staged deployments.
- There is no adjustment for the passage of the ship to the subsea cable starting position at Latheron – this can be added later once that detail is known.
- The leg between Nairn and Cruden Bay, whilst using terrestrial cable will still require the cable ship to sail to Cruden Bay and so the distance is included in the total GHGe calculation.

Limitations

Modern fibre optic systems are composed of a number of key components. Given a lack of data, timescales (budget) and the relative emissions value for components versus fuel, the physical elements of the cable system have not been included in this assessment but should assessed in any subsequent phase of work. An assessment of the following elements, including their transportation, is not directly captured in this report:

- the submarine cable;
- branching units (although the cable length has been noted and included);
- submarine line terminal equipment (SLTE);
- the power feed equipment; and
- power (electricity – although this is likely to tend towards 100% renewable).

Similarly the landing stages and the costs for their construction have not been included in the assessment due to a lack of verifiable/accessible data and limitations on time and budget in which to create a FarrPoint methodology for calculating the GHGe value.

Appendix 5: 5. Outputs

Summary of Main Report Recommendation

The main report recommends a hybrid approach to deliver the required connectivity to the named locations across Scotland and into the North East of England. A terrestrial link, using new or existing infrastructure, is proposed from Thurso to Latheron and from Nairn to Cruden Bay to account for some of the wider environmental, technical and cost issues of a marine only solution highlighted in the main report. As a result, there are two sections requiring land based dark fibre with the remaining links using a subsea option.

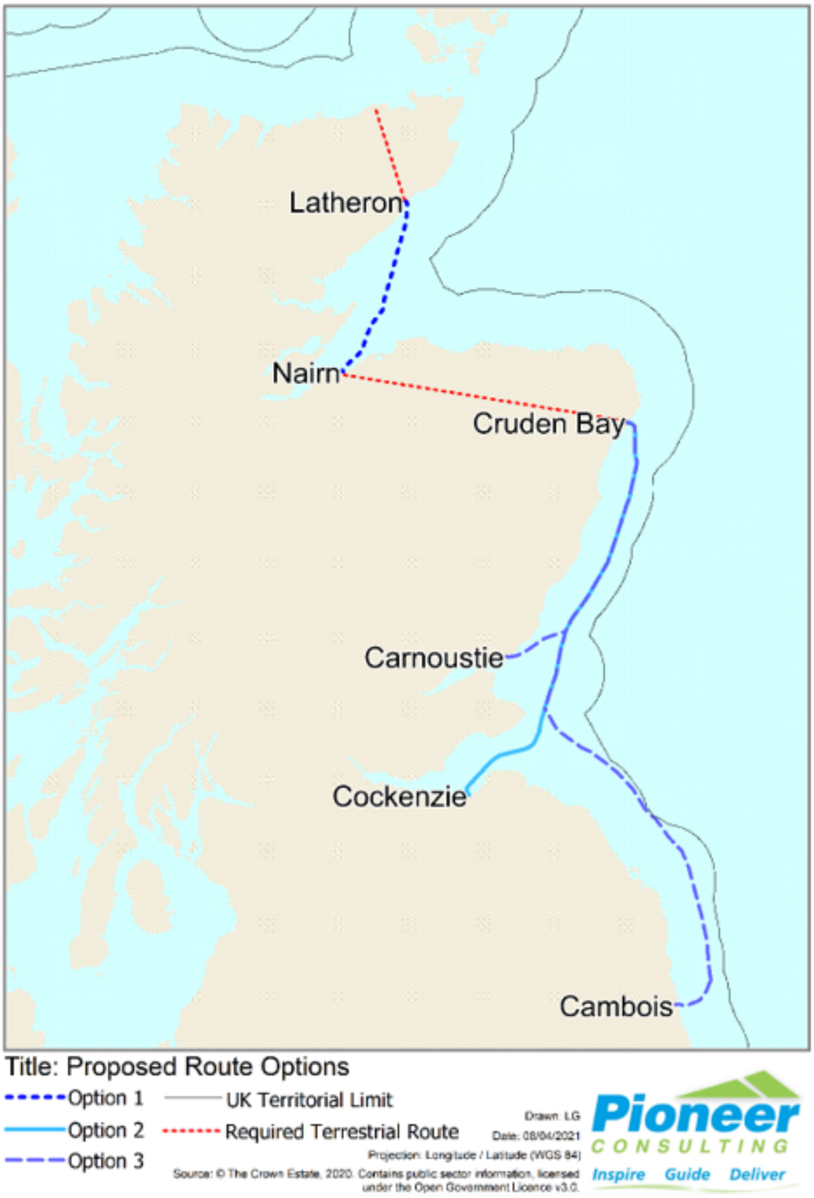

Figure A5.1: (Figure 36 from the main report – Proposed Route Options)

Terrestrial Routes and Availability

As part of this assessment the potential terrestrial routes from Thurso have been identified. From the total distance there are only three sections that will need new ducting and fibre. From FarrPoint analysis the remaining sections all have the ability to either use existing ducting infrastructure or have a commercially available solution using existing supplier fibres.

Route	Distance (km) along existing fibre only	Estimate of new build fibre needed (km)
Thurso-Latheron	62km	28km
Latheron-Nairn	162km	
Nairn-Cruden Bay	158km	38km
Cruden Bay-Carnoustie	125km	
Carnoustie-Cockenzie	122km	
Cockenzie-Cambois	153km (To Morpeth, no existing fibre in to Cambois)	11km

Table A5.1: Route Options and Fibre Availability

From Table A5.1, both the subsea option and a full terrestrial option will require a total of up to 77km of new fibre and civils.

Route Sections – Hybrid Options

Table A5.2 describes the cable site-to-site distances in sections. There are two options in the table denoted as section 4. Sections 1 -3 are common to both options. Section 4a is a route from Cruden Bay to Cockenzie with a spur to Carnoustie. Section 4b is a route from Cruden Bay to Cambois and on to the Termination Point, with two spurs: one to Carnoustie and the other to Cockenzie.

Section	Proposed Route	Distance (km)
1	Thurso ➔ Latheron	62 terrestrial
2	Latheron ➔ Nairn	80 subsea
3	Nairn ➔ Cruden Bay	158 terrestrial and 210 sailing
4a	Cruden Bay ➔ Cockenzie	188 subsea

Section	Proposed Route	Distance (km)
4a(i	Carnoustie spur	56 subsea
4a(ii	Return Journey	400
4b	Cruden Bay ➔ Cambois	299 subsea
4b(i	Carnoustie spur	56 subsea
4b(ii	Cockenzie spur	112 subsea
4b(iii	Cambois ➔ Termination Point	20 terrestrial
4b(iv	Return Journey	515

Table A5.2: Hybrid Route Sections and Distances

Hybrid Route Summary

Table A5.3 describes the total distances and the subdivisions of subsea and terrestrial required for both options.

Proposed Routes	Distance (km) Subsea	Distance (km) Terrestrial	Of which requires New Build fibre (km)	Total Distance (km)
1. Thurso ➔ Cockenzie (incl. spur)	534	220	66	754
Return Journey	400			1,154
2. Thurso ➔ Termination Point (incl. spurs)	757	240	77	997
Return Journey	515			1,512

Table A5.3: Total Distance

GHGe: Hybrid Subsea Options

To calculate the full emissions value of the proposed options, asset recovery must also be considered and modelled. At the end of the asset life it is common practise to remove undersea cables. For the purposes of the GHGe calculation it has been assumed, with evidence from e.g. Orange Marine[4], that new ships will be around 25% more efficient in their use of HFO and the CO_2 calculation has been adjusted accordingly.

Option 1: Thurso to Cockenzie with a spur to Carnoustie

Route / (Type)	Distance (km)	tCO_2e	Asset recovery (tCO_2e)
Thurso ➔ Latheron (T)	62	429	
Latheron ➔ Nairn (S)	80	517	388
Nairn ➔ Cruden Bay (S)	210	1,357	1,018
Nairn ➔ Cruden Bay (T)	158	582	
Cruden Bay ➔ Cockenzie (S)	188	1,215	911
Carnoustie spur (S)	56	362	271
Return (S)	400	2,584	1,938
TOTAL		7,046	4,526

Table A5.4: Option 1 CO_2 values

This gives a total CO_2 for option 1 of **11,572 tCO_2e.**

Option 2: Thurso to Cambois, with spurs to Carnoustie and Cockenzie

Route / (Type)	Distance (km)	tCO_2e	Asset recovery (tCO_2e)
Thurso ➔ Latheron (T)	62	429	
Latheron ➔ Nairn (S)	80	517	388
Nairn ➔ Cruden Bay (S)	210	1,357	1,018
Nairn ➔ Cruden Bay (T)	158	582	
Cruden Bay ➔ Cambois (S)	299	1,932	1,449
Carnoustie spur (S)	56	362	271
Cockenzie spur (S)	112	724	543
Cambois ➔ Termination Point (T)	20	168	
Return (S)	515	3,327	2,495
TOTAL		9,398	6,164

[4] https://www.capacitymedia.com/articles/3827104/orange-to-build-a-new-subsea-cable-ship-through-orange-marine

Table A5.5: Option 2 CO_2 values

This gives a total CO_2 for option 2 of **15,562 tCO_2e.**

GHGe: End-to-End Terrestrial Option

There is a third method to improve connectivity across the same geographic locations identified in the options considered for the hybrid approach. This method would involve using a full terrestrial approach to deploy new fibre from Thurso to Cockenzie as per *hybrid option 1*, or Thurso to the Termination Point from Cambois, as per *hybrid option 2*. As detailed in Table A5. 1, up to 77km of new build fibre would be required, with the remaining requirements met by either new fibre in existing infrastructure or the use of existing available fibre capacity.

The GHGe calculation for the deployment of the end-to-end solutions aligning with the hybrid option destination points is summarised in Table A5.6 below:

Proposed Routes	Terrestrial (tCO_2e)
1. Thurso ➔ Cockenzie	1,011
2. Thurso ➔ Cambios incl. Termination	1,179

Table A5.6: CO_2 values for terrestrial options.

Appendix 5: 6. Summary

Modelled CO_2 Equivalent by Hybrid Option

Table A5.7 sets out in summary the cost in GHGe/CO_2 for the two hybrid options proposed.

Proposed **Routes**	Distance (km) Subsea	Distance (km) Terrestrial	Total Distance (km)	tCO_2e	tCO_2e including recovery
1 Thurso ➔ Cockenzie	934	220	**1,154**	**7,046**	**11,572**
2 Thurso ➔ Cambios incl. Termination	1,272	240	**1,512**	**9,398**	**15,562**

Table A5.7 : GHGe – Option Summary

Option Comparison – Subsea vs. Terrestrial Build

The comparison in Table A5.8 below assumes that there is capacity in the ducts along all the routes required for the full terrestrial build with the exception of those captured in previous analysis. That is only 66km of new build is required for option 1, and 77km for option 2.

Proposed Routes	Hybrid Subsea (tCO_2e)	Hybrid Subsea (tCO_2e) including recovery	Terrestrial (tCO_2e)
1 Thurso ➔ Cockenzie	7,046	11,572	1,011
2 Thurso ➔ Cambios incl. Termination	9,398	15,562	1,179

Table A5.8: GHGe – Terrestrial vs. Subsea Comparison

Version Control

Owner **Andrew Muir**

Classification **Public**

Revision	Description	Author	Checked	Reviewed	Authorised	Date
1.0	Issued as Draft	AM	KV	KV	AM	16/04/21
1.1	Updated Draft	AM	KV	KV	AM	12/05/21
1.2	Final Issue	AM	KV	KV	AM	22/06/21

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